Interactive implementation of the Optimal Systems Control Program (OPTSYSX) on the IBM 3033.

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THESIS

INTERACTIVE IMPLEMENTATION OF THE
OPTIMAL SYSTEMS CONTROL DESIGN PROGRAM (OPTSYSX)
ON THE IBM 3033

by

John Gustav Hoden II

March 1984

Thesis Advisor: Daniel J. Collins

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The modified FORTRAN program (OPTSYSX) is now designed to run completely interactively under VM/CMS on the IBM 3033 and is considered completely compatible with similar operating systems.

Program capabilities include: complete eigensystem analysis; the ability to perform computations on very large multi-variable systems: controller, filter, regulator and compensator synthesis; transfer function analysis; steady-state gain determinations; and modal analysis.

The program permits users to rapidly carry out simulation, analysis, and design of all classes of optimal systems control problems in a totally interactive mode. Examples of various types of problems are worked out during individual terminal sessions.

Interactive Implementation of the Optimal Systems Control Program (OPTSYSX) on the IBM/3033

by

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ABSTRACT

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SYMBOLS

A =	state (Ns,Ns) or output (No,No) weighting matrix
B =	control (Nc,Nc) weighting matrix
C =	control gain matrix (Nc,Ns)
D =	control (Nc,Nc) or noise (No,Ng) feedforward matrix
E =	expected value
F =	open-loop dynamics matrix (Ns,Ns)
G =	control distribution matrix (Ns,Nc)
GAM =	state disturbance distribution matrix (Ns,Ng)
H =	measurement scaling matrix (No,Ns)
K =	estimator gain matrix (Ns,Nob)
Nc =	number of controls
Ng =	number of process noise sources
Ns =	number of states
No =	number of observations or measurements
P =	covariance matrix of estimate error (Ns,Ns)
Q =	white process noise covariance matrix (Ng,Ng)
R =	white meas. noise covariance matrix (No,No)
S =	steady-state covariance matrix of control (Nc,Nc)
u =	control vector (Nc,1)
v =	white measurement noise vector (No,1), with zero mean and covariance matrix R
w =	white process noise vector (Ng,1), with zero mean and covariance matrix Q
w0 =	constant disturbance vector (Ng,1)
x =	state vector (Ns,1)
xe =	estimate of state vector (Ns,1)
y =	output/measurement vector (No,1)

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I wish to dedicate this thesis to my wife, Brenda. Without her constant love, support, and understanding this work would not have been possible.

I. INTRODUCTION

The purpose of this thesis is to describe the extensive modification and improvement of an existing FORTRAN program (OPTSYS) used in the study, design, and application of Optimal Systems Control theory.

This optimal systems control program was originally developed by Hall [Ref. 1] in 1971 to support his research in rotary-wing VTOL aircraft control systems. The latest program modifications were made by Walker [Ref. 2] and Liu [Ref. 3] of Stanford University, to OPTSYS 4 and OPTSYS 5 respectively. These program versions performed quite satisfactorily in the batch environment, but exhibited varying degrees of user hostility due to data input format requirements and incomplete program documentation.

. The original intent of this work was to adapt Walker's modified version of OPTSYS to run interactively under VM/CMS on the IBM 3033; however, the extensive modifications of OPTSYSX now represent a high-level interactive applications software system capable of integrated simulation, analysis, synthesis and design of broad classes of optimal systems control problems. With OPTSYSX users may now evaluate various specialized optimal systems control applications, relieved of the burden of lengthy mathematical program development.

It is assumed that the reader/user is familiar with the basic concepts of Control Theory and Optimal Systems Design. The problem descriptions and program development follow the terminology and symbol/naming conventions of Bryson [Ref. 4].

An explanation of the basic system of equations, the terms and symbology used, and a program overview including the general methods of solution are presented first.

Interactive program development is then discussed, with an explanation of several alternate options available for data input.

This work concludes with examples of various types of problems demonstrated in the interactive mode, including a copy of each terminal session with the final results. A complete program listing is included in Appendix A.

II. THE OPTSYSX COMPUTER PROGRAM

A. INTRODUCTION

OPTSYSX is a double-precision FORTRAN program employing modern control theory analysis techniques. Although the program was originally written to synthesize controllers for rotary-wing VTOL aircraft [Ref. 5], it has been extensively modified to enable controller, filter, and regulator synthesis as well as transfer function and modal analysis on other types of large, multi-variable systems of equations. The program modifications described in this work now allow rapid numerical computer analysis in a completely interactive mode.

B. SYSTEM/MODEL DESCRIPTION

OPTSYSX treats a linear stationary system model:

$$\dot{x} = [F]x + [G]u + [GAMMA]w \qquad (2.1)$$

output equation

$$y = [H]x + [D]u \qquad (2.2)$$

measurement equation

$$z = [H]x + [D]w + v \qquad (2.3)$$

where

- u = control vector (m X 1)
- v = white measurement noise vector (p X 1)
- w = white process noise vector (q X 1)
- x = state vector (n X 1)

y = output vector (p X 1)

z = measurement vector (q X 1)

[F] is the open-loop dynamics matrix (system matrix or plant matrix); [G] is the control distribution matrix; [GAMMA] is the process noise distribution matrix; [H] is the measurement distribution matrix; and and [D] may represent a feed-forward distribution matrix of either the process noise vector (w), or the control vector (u).

The w vector has zero mean value, and a covariance matrix [Q], where:

$$E(w) = 0 \tag{2.4}$$

and

$$[Q] = E[ww^T] \tag{2.5}$$

The v vector has zero mean value and a covariance matrix [R], where:

$$E(v) = 0 \tag{2.6}$$

and

$$[R] = E[vv^T] \tag{2.7}$$

The quadratic performance (or cost) index for the linear quadradic regulator is the expected value of:

$$J = 1/2\int\{y^T[A]y + u^T[B]u\}dt \tag{2.8}$$

in the statistical steady-state, where [A] represents an output cost matrix (a weighting on the output variables);

and [B] is a control cost (or control weighting coefficient) matrix.

If full state weighting is desired, [H] is represented by the identity matrix [I].

C. PROGRAM OUTPUT

1. Open-Loop Eigensystem Calculations

The initial portion of OPTSYSX output includes the program flow control flags set by the user for that particular run, the system of equations being modeled, and the open-loop eigenvalue and eigenvector calculations of the [F] matrix.

2. Regulator Synthesis Calculations

In the solution to the optimal regulator problem, full state variable feedback is assumed where:

$$[C] = [B^{-1}][G^{T}][S] \qquad (2.9)$$

and

$$u = -[C]x \qquad (2.10)$$

The control gain [C] is a matrix of optimal gains which minimize the cost index expressed in equation (2.8).

For optimal regulator synthesis problems, program output includes the closed-loop eigenvalues and eigenvectors; the control gain [C]; the closed-loop dynamics matrix [F-GC]; and the steady-state gain matrix [S], where [S] is the steady-state solution to the algebraic Riccati equation:

$$S[F] + [F^{T}]S - S[G][B^{-1}][G^{T}]S + [H^{T}][A][H] = 0 \qquad (2.11)$$

3. Filter Synthesis Calculations

A Kalman filter or Estimator which describes a continuous time system may be written as:

$$\dot{\hat{x}} = [F]\hat{x} + [K](z - [H]\hat{x}) \qquad (2.12)$$

where:

$\hat{x}$ is the state estimate

[K] is a matrix of filter gains,

and the state covariance is described by:

$$E(xx^T) = E(\hat{x}\hat{x}^T) + [P] \qquad (2.13)$$

The filter gain matrix [K] of equation (2.12) is obtained from the relationship:

$$[K] = [P][H^T][R^{-1}] \qquad (2.14)$$

where [P] is the steady-state solution to the algebraic Riccati equation:

$$[F]P + P[F^T] - P[H^T][R^{-1}][H]P + [G][Q][G^T] = 0 \qquad (2.15)$$

representing the error covariance of the estimate $\hat{x}$. The control covariance is the expected value described by:

$$E(uu^T) = [C]\hat{x}[C^T] \qquad (2.16)$$

For the Kalman filter/optimal estimator synthesis problem, OPTSYSX output includes the eigenvalues and eigenvectors of the optimal estimator (Kalman filter); the filter gains [K]; the error covariance matrix [P]; the covariance

matrix of the estimate $[\hat{x}]$; the state covariance matrix $[X]$ described in equation (2.13), where

$$[X] = E[xx^T] \qquad (2.17)$$

and the control covariance matrix $[U]$ described in equation (2.16).

4. Stationary Closed-Loop Calculations

The stationary response of both state and control are presented as root-mean-square values of the state and control covariance matrices $[X]$ and $[U]$ described in equations (2.17) and (2.16) respectively.

D. SOLUTION ALGORITHM

One of the fundamental techniques necessary to quadratic synthesis of optimal control systems is the steady-state solution of the algebraic Riccati equation. This is a non-trivial task due to the iterative nature of the solution.

The steady-state solution by any quadrature method necessitates time increment selection no greater than some fraction of the shortest period of the closed-loop system; imposing a significant computer solution time expenditure on the user as well as the requiring an extensive amount of computer storage capability due to the matrix expansion factor involved. Further, the possible necessity of a time-varying solution of these equations for optimal open loop control or estimation requires the inversion of an n X n matrix for each time increment where an unsteady solution is desired.

A powerful and efficient alternate method of solution was developed by Bryson and Hall [Ref. 7], based on eigen-vector decomposition of the eigensystem of the constant coefficient EULER-LAGRANGE equations.

For the optimal regulator, these equations take the form:

$$\begin{bmatrix} \dot{x} \\ \dot{\lambda} \end{bmatrix} \begin{matrix} = \\ = \end{matrix} \begin{bmatrix} F & G^T B^{-1} G \\ A & -F^T \end{bmatrix} \begin{bmatrix} x \\ \lambda \end{bmatrix}$$

For the optimal filter or estimator, the equations are of the form:

$$\begin{bmatrix} \dot{x} \\ \dot{\lambda} \end{bmatrix} \begin{matrix} = \\ = \end{matrix} \begin{bmatrix} F & Gam*Q*Gam^T \\ H^T R^{-1} H & -F^T \end{bmatrix} \begin{bmatrix} x \\ \lambda \end{bmatrix}$$

OPTSYSX, and all earlier program versions, use the method of eigenvector decomposition of the EULER-LAGRANGE equations described in [Ref. 7] for quadratic synthesis of control systems. Program calculations are based on the QR algorithm of Francis, modified by Wilkinson [Ref. 8]. Important features of this method of eigensystem analysis are its improved accuracy, and its insensitivity to widely separated eigenvalues.

A more detailed description of the QR algorithm and its numerical applications to eigensystem analysis may be found in [Ref. 8].

E. PROGRAM OVERVIEW

OPTSYSX and its 41 subroutines may be divided into three basic categories:

1) setup and computation sequencing
2) data input
3) calculation

A brief and general description of the program modules and subroutines supporting these basic categories concludes this section.

1. Problem Description/Program Flow Control

The MAIN program allows interactive selection of all program flow control flags, and is aided by three subroutines : RDREAL, RDINT, and RDCHAR. A detailed description of these subroutines is provided in Chapter III. Subroutine CHECK verifies the consistency of all requested program options.

2. Interactive Data Input

Interactive data input is performed by the 14 READ__ subroutines. A detailed description of the operation of these subroutines is also included in Chapter III. Internal data generation or external data input is provided by subroutine SETUP.

3. Calculation Sequencing

Subroutine INNER functions as a second MAIN program. It orders the data input/calculation sequences for the type of problem being solved and performs numerous matrix calculations. It is from this subroutine that all input and calculation sequences are ordered and performed.

4. QR Algorithm Transformation

Subroutines MINV, BALANC, ORTHES, ORTRAN, HQR, HQR2, BALBAK, CNORM, and EREXIT perform the major calculation sequences of the "QR" algorithm.

5. Riccati Equation Calculations

Subroutine RGAIN separates the eigenvalues and eigenvectors of the Euler-Lagrange equations by eigenvector decomposition. RGAIN and subroutine SCOV calculate the steady-state solution of the Riccati equations for the controller or estimator problem. Subroutine SCOV computes

the covariance matrix solution to the algebraic Ricatti equation.

6. Modal Calculations

Subroutine MODE computes the modal transformations required for modal analysis.

7. Transfer Function Calculations

Subroutines TF, POLES, ZEROS, RESID, ACOMP, CCOMP, EQR, and Function SCI perform transfer function computations associated with Modal calculation sequences. Subroutine PSDCAL computes the power spectral density of the outputs or controls of a controlled system.

8. Data Output

Subroutine RAPRNT prints all program calculations in object time format. Subroutine MATPRT allows variable format screen viewing of all interactive matrix data input.

III. INTERACTIVE PROGRAM OPERATION

A. DESIGN CONSIDERATIONS

During the development of OPTSYSX, all program modifications and additions were focused primarily toward interactive user operation. Experience has demonstrated that interactive computer communication offers many advantages in the research and problem solving environment. The opportunity for flexible and immediate computer communication, as well as the ability to select alternate solution methods, are significant advantages to the user; advantages which are unavailable in a batch processing environment.

Although previous versions of OPTSYS produced all the desired calculations in the batch environment, the input format and data sequencing and naming conventions were confusing to many users. The user was burdened with the necessity of verifying the correctness of input data format and program flow control flag settings for each program run, in order to ensure the desired calculation sequence was properly performed.

These requirements, combined with incomplete program documentation, promoted a lack of confidence in the results and discouraged many potential users from even attempting to use OPTSYS.

B. PROGRAM LANGUAGE

OPTSYSX is programmed in FORTRAN IV, following the conventions of IBM System/360/370 FORTRAN IV language. Very few program features have been been incorporated which are not written in ANSI Standard FORTRAN. These subtle differences notwithstanding, OPTSYSX has been compiled and run

under both FORTRAN IV (G1) and FORTRAN H (Extended) compilers on the IBM 3033. Although the overall program length is in excess of 2800 lines of text, it is considered completely portable from one operating system to another.

On the presumption that most scientific and research personnel are familiar with FORTRAN language, program modifications may be easily undertaken once system operation is understood.

C. GENERAL PROGRAM MODIFICATIONS

All of the previously developed numerical calculation sequences of OPTSYS were retained un-modified in OPTSYSX.

Those program sequences requiring the input of diagonal cost or covariance matrix elements were deleted or modified to improve user flexibility in entering any desired weighting matrix, diagonal or otherwise. This modification streamlined program operation through elimination of several program flow control flags; reduced a measure of user uncertainty; and further decreased the required degree of user program familiarity--promoting uninterrupted operation.

The READ subroutines represent variations on the principle of simple, effective methods of interactive input, coupled with error-correction/recovery sequences.

Subroutines RDCHAR, RDINT, and RDREAL were developed by the author and Cdr. P.D. Sullivan to accomodate varying input format requirements; null-string entry protection was developed by Cdr. P.D. Sullivan. These program features are discussed in greater detail later in this chapter.

D. INTERACTIVE PROGRAM DEVELOPMENT

1. Program Flow Control

Initial program development required an understanding of the various problem descriptions as well as program input and calculation sequence. After careful analysis of [Ref. 2], a basic program flow control diagram was established. From this flow control diagram, a logical branching network was formulated whose path could be determined through either binary logic or numerical selection.

Three basic branching categories were established from the various problem description statements:

Logical--------{"Yes" or "No"..}
Integer--------{"1","2",etc...}
Real Number----{"Input the value of...}

From the viewpoint of free-format computer communication, integer and real number input presented no significant problems. FORTRAN compiler language is written such that numerical data input (real number or integer) is expected, thereby requiring only an INTEGER or REAL data type statement within the program. Once the data type has been declared, the desired values may then be input with a free-format READ (5,*) statement.

One note of caution concerning numerical data input in free-format deserves mentioning: Although all FORTRAN compilers treat character string input as an illegal data type conversion, many will automatically convert the inadvertent character entry to a "zero" and continue execution. Protection against inadvertent errors of this type is discussed later in this chapter.

Logical input ("Yes" or "No") poses a unique problem to programmers. The usual method of incorporation is to require the user to convert the logical answer into an integer i.e., "Yes" = 1, "No" = 2. These integers may then be read directly into the program, determining program flow.

Although this method may promote programming ease, it requires the user to adopt an unnatural habit pattern--one which increases the possibility of abnormal program termination in the event of inadvertent user error.

A more refined (from a programming language standpoint) and ergonomic (from the user viewpoint) method of logical selection involves utilization of the entire character string answer as an input value. This method has been incorporated into OPTSYSX.

The logical strings ("Yes" and "No) are declared as character strings in a data type statement within the program or subprogram. A format statement is also included in the program or subprogram utilizing the "A"-field to specify the desired character field width. A REWIND statement is then incorporated in the specific program or subprogram immediately prior to each logical string input point. This REWIND statement allows the input device (the terminal screen in this case) to read the character string in the same manner as free-format data input. The character field width for this modification was established at A1, allowing streamlined operation with the user typing either "Y" or "Yes" for an affirmative reply; "N" or "No" for a negative reply.

2. General Input Sequencing Requirements

All data input to OPTSYSX is in matrix or vector format. This data input must be correlated in accordance with the problem description and then properly sequenced in order for the program to perform the desired calculations.

The original and modified OPTSYS programs [Ref. 2] and [Ref. 3] required not only problem description knowledge but complete user familiarity with the detailed calculation sequence of the program. The latter point was considered a significant disadvantage. Elimination of this disadvantage

was an area where interactive programming offered the greatest benefits to the potential user; ans it was toward this end that the remaining modifications of OPTSYSX were directed.

3. Interactive Data Input

In its calculation sequences, OPTSYSX requires the input of up to 14 unique matrices or vectors. Once the previously described program flow control diagram was constructed, data entry points for each matrix or vector were established. At each of the 16 program data entry points, the required input matrix or vector was determined. Fourteen input subroutines were added to the original program in order to accomodate interactive data entry.

These matrix input subroutines were written such that the user is first informed which specific matrix or vector is required; then prompted for the individual matrix element values. These values are then individually and sequentially entered from the terminal. Once the matrix or vector is filled, it is returned to the terminal screen for user verification and correction if necessary.

Interactive sequential data entry was programmed by means of a two-dimensional DO loop, with a terminal prompt of the matrix name and element position prior to the element value entry. Data element input is via a free-format READ (5,*) program statement.

Once the matrix data entry sequence is complete, that input matrix is returned to the terminal screen in variable format for user ease in row identification. With an arbitrary data field width of 12 characters, the maximum number of matrix elements available on an 80 column terminal screen is six. Provided the matrix column dimension is less than six, this restriction presented no programming format limitations.

For those matrices whose column dimension exceeded six, elements were progressively written on subsequent terminal lines. Once the matrix row is filled the screen is double-spaced, and element display is repeated in the same fashion. This method allows the user to view the matrix much as he would expect to see it, providing the advantage of ease in row and column identification.

Within CPTSYSX, subroutine MATPRT performs this variable-format print sequence. The print sequence was arbitrarily terminated with a matrix size of 16 X 16, presuming that users with larger systems of equations would select alternate forms of data input.

4. Saving Interactive Input

In most control system design problems, the system matrices generally remain relatively unchanged for a desired sequence of design calculations.

In order to relieve the user of the burden of repeated system entry in the interactive mode, several additional program flow control flags were added, allowing the option of saving the entire original system of matrices for subsequent calculations. Separate options for saving each system matrix are automatically offered at the end of each program run.

These matrix saving options provide a further advantage to the user in that the matrices are redisplayed for verification prior to calculation execution. Users may then change individual matrix elements, relieved of the burden of full system re-entry.

5. User-Defined Input Files

Although the basic objective of this work is to provide the user with a totally interactive method of data input, several disadvantages to the method of individual

matrix element input are apparent--input of very large matrices is unwieldy and time-consuming; input of systems of matrices whose elements remain unchanged from run to run is inefficient.

In order to provide an increased measure of user flexibility in data input, subroutine SETUP was modified to include provisions for matrix data input from a data file on the user's disk. The three system matrices, [F],[G], and [GAMMA] may now be input from the user's disk. Minor program modification is required of the user as follows:

a. FRICMS Filedef commands must be modified or added to reflect the name and location of each data set.

b. The READ Format statement (or statements) must be changed to reflect the proper data format of the user's input file.

6. Internal Data Generation

As a further measure of flexibility, the documentation within subroutine SETUP was expanded to include several specific examples of internal matrix data generation. The three system matrices [F], [G], and [GAMMA] may generated either within user-written two-dimensional DO-loops or by direct assignment statements. These methods may be preferable for the input of very large matrices with few non-zero elements.

A specific example of internal program generation of the output equation [H] matrix is included in subroutine READH. This matrix input method may be preferable for the entry of a large output equation matrix with very few non-zero elements.

Once these modifications have been made to subroutine SETUP or subroutine READH (as desired), the program should be re-compiled and then run in the usual manner. An

interactive program prompt is provided at the beginning of OPTSYSX offering the user the option of specifying the desired method of data input.

OPTSYSX was further modified to include the ability to input the [H] matrix (or other required input matrices) from separate data files. Users with rudimentary programming skills may now modify subroutine READH (or one of the other specific READ subroutines) in the manner previously described for subroutine SETUP or subroutine READH. Detailed examples of the nature and extent of these modifications may be found in Appendix A.

7. <u>Data Entry Correction</u>

In an effort to protect users from errors in data input, an error correction sequence was incorporated into each matrix input subroutine.

Once the entire matrix or vector is displayed on the terminal screen the user is prompted with the question, "Do you wish to change the value of any matrix element? Type 'Yes' or 'No'." If the user types "No", program execution continues.

If the user types "Yes", he is then prompted with three additional statements specifying the row number of the element to be changed, the column number of the element to be changed, and the value to be inserted into that matrix element. After the corrected value is entered, the new matrix values are returned to the screen for re-verification.

This correction sequence continues indefinitely until the user signifies that no additional changes are necessary. Program execution then proceeds normally.

E. USER-ERROR PROTECTION FEATURES

Many interactive computer programs suffer the irking characteristic of abnormal program termination (without recovery!) should the user inadvertently make an erroneous keyboard entry. Examples of these inadvertent errors include--entry of a keyboard character or character string when the program expects a numerical value; entry of a numerical value when the program is expecting a character string; entry of a null string. In order to preclude abnormal program termination due to these types of inadvertent user errors, several program protection features were incorporated into OPTSYSX.

1. Data Type Conversion Errors

Three subroutines--RDREAL, RDINT, RDCHAR--were added to OPTSYSX in order to ensure that the proper input data type is provided to the program. Subroutine RDREAL is called at any point a real number or zero integer inputmay be encountered; subroutine RDINT is called at any point a non-zero integer input is required; subroutine RDCHAR is called at any point a character string ("Yes" or "No") input is required.

Within each of these subroutines a null string entry protection loop was incorporated (allowing one recovery); prompting the user for the correct data type input, and returning an error message in the event an incorrect data type is encountered.

Within subroutine RDINT, improper data type entry was further protected by the addition of a three-way IF comparison of entry integer magnitude. This modification precludes illegal (but automatic, with some compilers) data type conversion errors.

These program design features boast the additional advantage of allowing normal program termination at any point in the data input phase by merely pressing the "Enter" key twice.

2. Inconsistent Program Control Flag Errors

Earlier versions of OPTSYS [Ref. 2] and [Ref. 3], did provide user error messages in the event of inconsistent program flow control flags, but terminated the program. This feature was undesirable from the standpoint of smooth interactive program operation, and was improved in OPTSYSX.

Subroutine CHECK was modified to include RETURN statements any time inconsistent program flow control flags are encountered. The user is notified of the type of error encountered; that run termination has occurred; and prompted regarding his desire to return to the beginning of the program or terminate execution completely.

IV. PROGRAM USE AND EXAMPLES

This chapter contains several basic examples of the numerous types of problems which may be solved using CPTSYSX. Included with these examples are copies of each recorded terminal session.

Potential users should examine carefully the example of program failure found in Section D. This example clearly demonstrates that unstable modes or incorrect choice of certain design parameters may cause program failure (and incorrect output!), even with the highly stable "QR" algorithm. It also indicates one possible method of correcting this type of failure by merely making a very small change to one of the design parameters.

A. OPEN-LOOP EIGENSYSTEM ANALYSIS

The following open-loop eigenvalue example was taken from [Ref. 9, p.669].

Examination of the following program output shows open-loop eigenvalues at -1, -2, and -3. Note that the eigenvectors of the left and right eigenvector matrices (pa. 33) correspond in column fashion to the open-loop eigenvalues calculated immediately above them (pa. 32).

The full terminal session is recorded below, with user input in lower case letters following each "?" .

```
record on
BEGIN RECORDING OF TERMINAL SESSION
R; T=0.01/0.02 21:49:30
filedef 06 term (recfm fa blksize 133
global txtlib fortmod2 mod2eeh imsldp nonimsl
load cptsysx (start
```

```
EXECUTICN BEGINS...
CPTSYSX IS A COMPLETELY INTERACTIVE OPTIMAL SYSTEMS CONTROL
    PROGRAM. IT WILL SCLVE NUMERCUS CONTROL PROBLEMS ON THE
    FCLLOWING TYPES CF SYSTEMS CCNTROL EQUATIONS:
           XDOT = (F)*X + (G)*U + (GAM)*(W+WO)
              MEASUREMENT EQUATION--
               Z = (H)*X + (D)*W
            REGULATOR PERFORMANCE INDEX--
        J = 1/2 * INTEGRAL (Yt*(A)*Y + Ut*(B)*U) DT
            STATE FEEDBACK GAIN DEFINITION--
                      U = -(C)*X
        DC YCU WISH TC CONTINUE?  TYPE "YES" OR "NO".
yes
                    --DATA ENTRY--
     ALTHCUGH OPISYSX IS SPECIFICALLY DESIGNED TO READ
     ALL MATRIX DATA INTERACTIVELY, SEVERAL ALTERNATE
     METHODS ARE AVAILABLE TC USERS:
    METHCD 1--THE "F","G", AND "GAMMA" MATRICES
              MAY BE READ FRCM SEPARATE DATA FILES.
    METHCD 2--THE "F","G", AND "GAMMA" MATRICES MAY BE
              EXPLICITLY DEFINED WITHIN SUBROUTINE "SETUP".
      (NCTE: IN EITHER CASE, THE USER SHOULD CBTAIN A CCPY
             OF THE PRCGRAM LISTING AND EXAMINE
             THE EXAMPLES CONTAINED IN S/R "SETUP".)
      DC YOU WISH TO CCNTINUE?  TYPE "YES" OR "NO".
yes
     DO YCU WISH TO INPUT THE "F", "G", AND "GAMMA"
         MATRICES FRCM SUBROUTINE "SETUP" IAW THE
         METHOD DESCRIBED CN THE PREVIOUS SCREEN?
              TYPE "YES" OR "NO".
nc
                   GENERAL OPISYSX OPTIONS:
        CPTION 1 -- SYSTEM ANALYSIS WITHOUT
                    CPEN-LOCP EIGENSYSTEM CALCULATIONS.
        CPTION 2 -- SYSTEM ANALYSIS WITH OPEN-LOOP
```

```
                    EIGENSYSTEM CALCULATIONS.
         OPTION 3 -- OPEN-LOOP EIGENSYSTEM FOUND
                    AND PROGRAM TERMINATES.
               ("F"-MATRIX ENTRY FOLLOWS IMMEDIATELY.)
         OPTION 4 -- MODAL DISTRIBUTION MATRICES COMPUTED
                    WITHOUT FILTER OR REGULATOR SYNTHESIS
                    OR STEADY-STATE ANALYSIS.
               SELECT AN OPTION: 1,2,3, OR 4.
?
3
    ENTER THE # OF STATES (NS) OF THE SYSTEM MATRIX
     "F"-MATRIX .
?
3
   FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:
IOL  IQ    IR  ISS   IM  ITF1  ITF2  ITF3 IFDFW IE IDEBUG
 2    0     0   0     0    0     0     0    0    0   0
ISET  IDSTAE  IPSD  IYU  INCRM  IREG  NS  NC  NOB  NG
  0     0       0    0     0      0    3   0   0    0

 ORDER OF SYSTEM =  3
 NUMBER OF CONTROLS =  0
 NUMBER OF OBSERVATIONS =  0
 NUMBER OF PROCESS NOISE SOURCES =  0

    ENTER THE SYSTEM MATRIX  "F"-MATRIX
        DIMENSION = # STATES (NS) X # STATES (NS)
    THE ELEMENT F( 1, 1)=
?
0
    THE ELEMENT F( 1, 2)=
?
1
    THE ELEMENT F( 1, 3)=
?
0
```

```
      THE ELEMENT F( 2, 1)=
?
C
      THE ELEMENT F( 2, 2)=
?
0
      THE ELEMENT F( 2, 3)=
?
1
      THE ELEMENT F( 3, 1)=
?
-6
      THE ELEMENT F( 3, 2)=
?
-11
      THE ELEMENT F( 3, 3)=
?
-6

                THE SYSTEM MATRIX  "F"-MATRIX ...
      C.C          1.0C000     0.0
      C.0          0.0          1.00000
    -6.CC000    -11.0C000    -6.00000

   DO YCU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" CR "NO".
n
    OPEN LCCP DYNAMICS MATRIX..................F..
   0.0             0.100CD+01   0.0
   0.C             0.0             0.1000D+01
  -0.60C0D+01  -0.110CD+02  -C.6000D+01

CPEN ICCP EIGENVALUES..........DET(SI-F)..
-1.00CC0D+0C:-2.0000CD+00:-3.00000D+00:
```

```
OPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....
-5.773503D-01 -2.182179D-01  1.048285D-01
 5.773503D-01  4.364358D-01 -3.144855D-01
-5.773503D-01 -8.728716D-01  9.434564D-01

OPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..
-5.196152D+00 -4.330127D+00 -8.660254D-01
 1.374773D+01  1.833030D+01  4.582576D+00
 9.539392D+00  1.430909D+01  4.769696D+00

     ANALYSIS COMPLETE. DO YOU WANT ANOTHER RUN?
               TYPE "YES" OR "NO".
no
  ......OPTSYSX IS NOW TERMINATED........

R; T=0.28/0.89 21:52:08
record off
END RECORDING OF TERMINAL SESSION
```

E. REGULATOR SYNTHESIS

The following regulator synthesis example was taken from "Lecture Notes on Advanced Control Systems", by Professor D.J. Collins of the Naval Postgraduate School, Monterey,Ca. This example involved determination of the optimal regulator gains based on an arbitrarily chosen quadratic index; with the various system and cost matrices described below.

Examination of the extensive program output indicates that the optimal regulator gains are: -5.0 and -SQRT(10.0). The algebraic sign of the gains is consistent with the definition displayed on the first screen of the program (pg. 34).

The full terminal session is recorded below, with user input in lower case letters following each "?" .

```
record on
BEGIN RECORDING OF TERMINAL SESSION
```

```
R; T=0.01/0.02 13:55:26
filedef 06 term (recfm fa blksize 133
global txtlib fortmod2 mod2eeh imsldp nonimsl
load optsysx (start
EXECUTION BEGINS...
OPTSYSX IS A COMPLETELY INTERACTIVE OPTIMAL SYSTEMS CONTROL
    PROGRAM. IT WILL SOLVE NUMEROUS CONTROL PROBLEMS ON THE
    FOLLOWING TYPES OF SYSTEMS CONTROL EQUATIONS:
          XDOT = (F)*X + (G)*U + (GAM)*(W+W0)
                MEASUREMENT EQUATION--
             Z = (H)*X + (D)*W + V
                REGULATOR PERFORMANCE INDEX--
             J = 1/2 * INTEGRAL (Yt*(A)*Y + Ut*(B)*U)DT
               STATE FEEDBACK GAIN DEFINITION--
                         U = -(C)*X
       DO YOU WISH TO CONTINUE?  TYPE "YES" OR "NO".
y
                        --DATA ENTRY--
     ALTHOUGH OPTSYSX IS SPECIFICALLY DESIGNED TO READ
     ALL MATRIX DATA INTERACTIVELY, SEVERAL ALTERNATE
     METHODS ARE AVAILABLE TO USERS:
      METHOD 1--THE "F","G", AND "GAMMA" MATRICES
                MAY BE READ FROM SEPARATE DATA FILES.
      METHOD 2--THE "F","G", AND "GAMMA" MATRICES MAY BE
             EXPLICITLY DEFINED WITHIN SUBROUTINE "SETUP".
      (NOTE: IN EITHER CASE, THE USER SHOULD OBTAIN A COPY
              OF THE PROGRAM LISTING AND EXAMINE
              THE EXAMPLES CONTAINED IN S/R "SETUP".)
        DO YOU WISH TO CONTINUE?  TYPE "YES" OR "NO".
y
        DO YOU WISH TO INPUT THE "F", "G", AND "GAMMA"
          MATRICES FROM SUBROUTINE "SETUP" IAW THE
          METHOD DESCRIBED ON THE PREVIOUS SCREEN?
               TYPE "YES" OR "NO".
n
```

```
                    GENERAL OPTSYSX OPTIONS:
        OPTION 1 -- SYSTEM ANALYSIS WITHOUT
                    OPEN-LOOP EIGENSYSTEM CALCULATIONS.
        OPTION 2 -- SYSTEM ANALYSIS WITH OPEN-LOOP
                    EIGENSYSTEM CALCULATIONS.
        OPTION 3 -- OPEN-LOOP EIGENSYSTEM FOUND
                    AND PROGRAM TERMINATES.
             ("F"-MATRIX ENTRY FOLLOWS IMMEDIATELY.)
        OPTION 4 -- MODAL DISTRIBUTION MATRICES COMPUTED
                    WITHOUT FILTER OR REGULATOR SYNTHESIS
                    OR STEADY-STATE ANALYSIS.
              SELECT AN OPTION: 1,2,3, OR 4.
?
2
    DO YOU DESIRE RMS VALUES OF STATE AND CONTROL?
        TYPE "YES" OR "NO".
NO
                    OPTSYSX LQR/CLASSICAL OPTIONS:
        OPTION 1 -- OPTIMAL FILTER AND/OR REGULATOR
                    SYNTHESIS WITH NO EXTERNAL "C" OR "K"
                    MATRIX INPUT.
        OPTION 2 -- OPTIMAL FILTER AND/OR REGULATOR
                    SYNTHESIS WITH EXTERNAL "C"
                    MATRIX INPUT.
        OPTION 3 -- OPTIMAL FILTER AND/OR REGULATOR
                    SYNTHESIS WITH EXTERNAL "K"
                    MATRIX INPUT.
        OPTION 4 -- OPTIMAL FILTER AND/OR REGULATOR
                    SYNTHESIS WITH EXTERNAL "C" AND "K"
                    MATRIX INPUT.
        SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
    DO YOU WISH TO DETERMINE THE STEADY-STATE RESPONSE
      FOR A CONSTANT DISTURBANCE?
```

```
          TYPE "YES" OR "NO".
NO
      DO YOU WISH TO DETERMINE THE MODAL DISTRIBUTION
         AND GAIN MATRICES?
          TYPE "YES" OR "NO".
NO
            OPEN-LOOP TRANSFER FUNCTION OPTIONS:
        OPTION 1 -- NO OPEN-LOOP TRANSFER FUNCTIONS COMPUTED.
        OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
        OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
        OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
           SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
            NOISE TRANSFER FUNCTION OPTIONS:
         OPTION 1 -- NO NOISE TRANSFER FUNCTIONS COMPUTED.
         OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
         OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
         OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
           SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
      COMPENSATOR TRANSFER FUNCTION OPTIONS:
         OPTION 1 -- NO COMP. TRANSFER FUNCTIONS COMPUTED.
         OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
         OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
         OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
            (NOTE: A COMPENSATOR TRANSFER FUNCTION CAN BE
                 COMPUTED ONLY IF BOTH A REGULATORAND
                 FILTER ARE SYNTHESIZED AND/OR INPUT.)
           SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
      WILL A FEED-FORWARD DISTRIBUTION MATRIX
         ("D" - MATRIX) BE INPUT ?
```

```
                  TYPE "YES" OR "NO".
no
 THIS OPTION DETERMINES THE CRITERIA FOR DECIDING WHEN A
 MARKOV PARAMETER IS ZERO-THE MARKOV PARAMETER INDICATES
 THE ORDER OF THE NUMERATOR POLYNOMIAL OF EACH TRANSFER
 FUNCTION.
    ALL "N" ZEROS OF THIS POLYNOMIAL ARE PRINTED OUT AND
    THIS TEST TELLS HOW MANY EXTRA ROOTS EXIST AT Z = 0.
    LESS THAN 10.0**(-IE) IS CONSIDERED ZERO.
    THE DEFAULT VALUE OF THIS PARAMETER (IE) IS 6.
       IN OTHER WORDS, IE = 1.0E-6.
    IF YOU DESIRE A DIFFERENT MARKOV CRITERIA, TYPE THE
      INTEGER VALUE.
    IF YOU DESIRE THE DEFAULT VALUE, TYPE "0" (ZERO)
?
0
 DO YOU DESIRE TO SYNTHESIZE A STABLE FILTER (OR REGULATOR)
 BY DESTABILIZING THE ORIGINAL SYSTEM?
        (NOTE:WORKS FOR FILTER OR REGULATOR BUT NOT FOR BOTH
              IN THE SAME RUN.)
           TYPE "YES" OR "NO".
no
     DO YOU DESIRE TO PRINT THE EULER-LAGRANGE EIGENSYSTEM
        PRIOR TO DECOMPOSITION (FOR CHECKING THE PROGRAM)?
           TYPE "YES" OR "NO".
yes
     POWER SPECTRAL DENSITY (PSD) OPTION 1 :
     OPTION 1 -- COMPUTE THE PSD OF THE OUTPUTS AND/OR THE
                 CONTROLS OF THE CONTROLLED SYSTEM WHEN
                 FORCED BY PROCESS AND MEASUREMENT NOISE.
             (NOTE: BOTH A REGULATOR AND A FILTER MUSTBE
              RESIDENT IN THE PROGRAM TO USE THIS OPTION.(
      OPTION 2 -- SAME AS OPTION 1 ABOVE BUT ONLY PRINT THE
                  RESIDUES OF EACH TRANSFER FUNCTION
                  USED IN THE PSD COMPUTATION.
```

```
      OPTION 3 -- NOT DESIRED.
           SELECT AN OPTION: 1, 2, OR 3.
?
3
     DO YOU DESIRE REGULATOR SYNTHESIS ONLY?
           TYPE "YES" OR "NO".
yes
     ENTER THE # OF STATES (NS) OF THE SYSTEM MATRIX
      ("F"-MATRIX).
?
2
  ENTER THE # OF CONTROLS (NC) OF THE CONTROL SYSTEM MODEL
    ("G"-MATRIX).
?
1
  ENTER THE # OF MEASUREMENTS OR OBSERVATIONS (NO) OF THE
   ("H"-MATRIX).
?
2
 ENTER THE # OF PROCESS NOISE SOURCES (NG) OF THE
 ("GAMMA"-MATRIX).
?
0
    FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:
IOL   IQ   IR   ISS   IM   ITF1   ITF2   ITF3   IFDFW   IE   IDEBUG
 1     0    0    0     0     0      0      0      0      0     1
ISET   IDSTAB   IPSD   IYU   INCRM   IREG   NS   NC   NOB   NG
 0      0        0      0      0       1     2    1    2    0
 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  2
 NUMBER OF PROCESS NOISE SOURCES =  0
     ENTER THE SYSTEM MATRIX  "F"-MATRIX
           DIMENSION = # STATES (NS) X # STATES (NS)
     THE ELEMENT F( 1, 1)=
```

```
?
0
      THE ELEMENT F( 1, 2)=
?
1
      THE ELEMENT F( 2, 1)=
?
0
      THE ELEMENT F( 2, 2)=
?
C
                 THE SYSTEM MATRIX  "F"-MATRIX ...
      C.0          1.0C000
      C.0          0.0
    DC YCU WISH TC CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" CR "NO".
NO
     CPEN LCCP DYNAMICS MATRIX.................F..
  0.C           0.1000D+01
  0.0           0.0

     CPEN LCCP EIGENVALUES..........DET(SI-F)..
 0.0         : 0.0         :

     CPEN LCCP RIGHT EIGENVECTCR MATRIX.......T....
 1.0C000CCD+00 -1.000CCCD+00
 0.0            2.220446D-16

     CPEN LCCP LEFT EIGENVECTOR MATRIX......T-INV..
 1.CCCCCCD+C0  4.5036C0D+15
 0.0           4.5036C0D+15

      ENTER THE MEASUREMENT SCALING MATRIX  "H"-MATRIX .
          DIMENSION = # CBSERVATIONS (NO) X # STATES (NS)
      THE ELEMENT H( 1, 1)=
?
1
```

```
     THE ELEMENT H( 1, 2)=
?
0
     THE ELEMENT H( 2, 1)=
?
0
     THE ELEMENT H( 2, 2)=
?
1
          THE MEASUREMENT SCALING MATRIX  "H"-MATRIX ...
     1.00000     0.0
     0.0         1.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
NO
    MEASUREMENT SCALING MATRIX................H..
  0.10000E+01   0.0
  0.0           0.10000E+01
     ENTER THE OUTPUT MEASUREMENT COST MATRIX  "A"-MATRIX .
     DIMENSION = # OBSERVATIONS (NO) X # OBSERVATIONS (NO)
     THE ELEMENT A( 1, 1)=
?
25
     THE ELEMENT A( 1, 2)=
?
0
     THE ELEMENT A( 2, 1)=
?
0
     THE ELEMENT A( 2, 2)=
?
0
     THE OUTPUT MEASUREMENT COST MATRIX  "A"-MATRIX ...
    25.00000     0.0
```

```
      0.0          0.0
      DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
           TYPE "YES" OR "NO".
NO
     OUTPUT COST MATRIX.......................A..
   0.2500D+02   0.0
   0.0          0.0

      ENTER THE CONTROL DISTRIBUTION MATRIX  "G"-MATRIX .
           DIMENSION = # STATES (NS) X # CONTROLS (NC)
      THE ELEMENT G( 1, 1)=
?
0
      THE ELEMENT G( 2, 1)=
?
1
           THE CONTROL DISTRIBUTION MATRIX  "G"-MATRIX ...
      0.0
      1.00000
    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
           TYPE "YES" OR "NO".
NO
      ENTER THE CONTROL COST WEIGHTING MATRIX  "B"-MATRIX
           DIMENSION = # CONTROLS (NC) X # CONTROLS (NC)
      THE ELEMENT B( 1, 1)=
?
1
           THE CONTROL COST MATRIX..........B...
      1.00000
    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
           TYPE "YES" OR "NO".
NO
     THE CONTROL DISTRIBUTION MATRIX..........G..
   0.0
   0.1000D+01
```

```
   THE CONTROL COST MATRIX....................B..
  0.1000D+01

    EULER-LAGRANGE SYSTEM MATRIX...
 0.0            1.000000D+00  0.0            0.0
 0.0            0.0           0.0           -1.000000D+00
-2.500000D+01   0.0           0.0            0.0
 0.0            0.0          -1.000000D+00   0.0

   EIGENVALUES AND EIGENVECTORS OF THE 2N X 2N
   EULER-LAGRANGE SYSTEM AFTER HQR2.............

-1.581139D+00 1.581139D+00
-1.581139D+00-1.581139D+00
 1.581139D+00 1.581139D+00
 1.581139D+00-1.581139D+00

-7.430443D-02  7.168812D-02 -1.824925D-01 -1.503482D-01
 4.136755D-03 -2.308345D-01 -5.082459D-02 -5.262675D-01
-1.154172D+00 -2.068377D-02  2.631337D+00 -2.541229D-01
-3.584406D-01 -3.715222D-01 -7.517412D-01  9.124627D-01

   EIGENSYSTEM OF OPTIMAL REGULATOR.........

    EIGENVECTORS FROM RGAIN PRIOR TO CNORM
-1.459925D-01 -2.616313D-03
 2.349712D-01 -2.266977D-01

   C-LOOP OPTIMAL REG. E-VALUES...DET(SI-F+G*C)..
-1.58114D+00, 1.58114D+00:

   C-LOOP RIGHT EIGENVECTOR MATRIX...........M....
-3.162278D-01 -3.162278D-01
 1.000000D+00  0.0

   CONTROL EIGENVECTOR MATRIX...............C*M..
  -1.581139D+00  1.581139D+00
```

```
    C-LOOP OPT. REG. LEFT E-VECTOR MATRIX..M-INV..
 0.0            1.000000D+00
-3.162278D+00 -1.000000D+00

 THE OPTIMAL FEEDBACK GAIN CONTROL MATRIX...C=B[illegible]*G_*S...
 -5.0000D+00  -3.1623D+00

    THE CLOSED LOOP DYNAMICS MATRIX ......F-G*C..
 0.0            1.000000D+00
-5.000000D+00 -3.162278D+00

     ANALYSIS COMPLETE. DO YOU WANT ANOTHER RUN?
               TYPE "YES" OR "NO".
no
    ........OPTSYSX IS NOW TERMINATED........

R; T=0.42/1.85 14:03:03
record off
END RECORDING OF TERMINAL SESSION
```

C. FILTER SYNTHESIS

The following Kalman filter synthesis example was taken from "Lecture Notes on Advanced Control Systems", by Professor D.J. Collins of the Naval Postgraduate School, Monterey,Ca.

This example involved determination of the optimal filter gains of an arbitrary system; modeled nearly identically to the previous regulator problem.

In its present configuration, OPTSYSX program sequencing requires the design of an optimal regulator, prior to performing any optimal estimator synthesis. In order to comply with built-in program sequencing conventions, and circumvent program difficulties which may not be specified in the particular system model, optimal filter synthesis may be accomplished by entering the identity matrix [I] in those

program input sequences requiring the entry of an output cost (weighting) matrix. Although the optimal regulator calculations may differ from those expected, the optimal estimator calculations will be correct for the system model.

Examination of the extensive program output indicates that the optimal filter gains are: -5.0, and -SQRT(2.0).

The full terminal session is recorded below, with user input in lower case letters following each "?" .

```
record on
BEGIN RECORDING OF TERMINAL SESSION
R; T=0.01/0.02 21:49:30
filedef 06 term (recfm fa blksize 133
global txtlib fortmod2 mod2eeh imsldp nonimsl
load optsysx (start
EXECUTION BEGINS...
 OPTSYSX IS A COMPLETELY INTERACTIVE OPTIMAL SYSTEMS CONTROL
     PROGRAM. IT WILL SOLVE NUMEROUS CONTROL PROBLEMS ON THE
     FOLLOWING TYPES OF SYSTEMS CONTROL EQUATIONS:
             XDOT = (F)*X + (G)*U + (GAM)*(W+W0)
                  MEASUREMENT EQUATION--
                Z = (H)*X + (D)*W + V
                  REGULATOR PERFORMANCE INDEX--
                J = 1/2 * INTEGRAL (Yt*(A)*Y + Ut*(B)*U)DT
                  STATE FEEDBACK GAIN DEFINITION--
                          U = -(C)*X
             DO YOU WISH TO CONTINUE?  TYPE "YES" OR "NO".
yes
                          --DATA ENTRY--
     ALTHOUGH OPTSYSX IS SPECIFICALLY DESIGNED TO READ
     ALL MATRIX DATA INTERACTIVELY, SEVERAL ALTERNATE
     METHODS ARE AVAILABLE TO USERS:
       METHOD 1--THE "F","G", AND "GAMMA" MATRICES
             MAY BE READ FROM SEPARATE DATA FILES.
       METHOD 2--THE "F","G", AND "GAMMA" MATRICES MAY BE
```

```
               EXPLICITLY DEFINED WITHIN SUBROUTINE "SETUP".
          (NOTE: IN EITHER CASE, THE USER SHOULD OBTAIN A COPY
                  OF THE PROGRAM LISTING AND EXAMINE
                  THE EXAMPLES CONTAINED IN S/R "SETUP".)
          DO YOU WISH TO CONTINUE?  TYPE "YES" OR "NO".
yes
     DO YOU WISH TO INPUT THE "F", "G", AND "GAMMA"
          MATRICES FROM SUBROUTINE "SETUP" IAW THE
          METHOD DESCRIBED ON THE PREVIOUS SCREEN?
               TYPE "YES" OR "NO".
no
                    GENERAL OPTSYSX OPTIONS:
          OPTION 1 -- SYSTEM ANALYSIS WITHOUT
                      OPEN-LOOP EIGENSYSTEM CALCULATIONS.
          OPTION 2 -- SYSTEM ANALYSIS WITH OPEN-LOOP
                      EIGENSYSTEM CALCULATIONS.
          OPTION 3 -- OPEN-LOOP EIGENSYSTEM FOUND
                      AND PROGRAM TERMINATES.
               ("F"-MATRIX ENTRY FOLLOWS IMMEDIATELY.)
          OPTION 4 -- MODAL DISTRIBUTION MATRICES COMPUTED
                      WITHOUT FILTER OR REGULATOR SYNTHESIS
                      OR STEADY-STATE ANALYSIS.
               SELECT AN OPTION: 1,2,3, OR 4.
?
1
     DO YOU DESIRE RMS VALUES OF STATE AND CONTROL?
          TYPE "YES" OR "NO".
no
                     OPTSYSX LQG/CLASSICAL OPTIONS:
            OPTION 1 -- OPTIMAL FILTER AND/OR REGULATOR
                        SYNTHESIS WITH NO EXTERNAL "C" OR "K"
                        MATRIX INPUT.
            OPTION 2 -- OPTIMAL FILTER AND/OR REGULATOR
                        SYNTHESIS WITH EXTERNAL "C"
                        MATRIX INPUT.
```

```
        OPTION 3 -- OPTIMAL FILTER AND/OR REGULATOR
                    SYNTHESIS WITH EXTERNAL "K"
                    MATRIX INPUT.
        OPTION 4 -- OPTIMAL FILTER AND/OR REGULATOR
                    SYNTHESIS WITH EXTERNAL "C" AND "K"
                    MATRIX INPUT.
        SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
     DO YOU WISH TO DETERMINE THE STEADY-STATE RESPONSE
       FOR A CONSTANT DISTURBANCE?
        TYPE "YES" OR "NO".
no
     DO YOU WISH TO DETERMINE THE MODAL DISTRIBUTION
       AND GAIN MATRICES?
        TYPE "YES" OR "NO".
no
     OPEN-LOOP TRANSFER FUNCTION OPTIONS:
      OPTION 1 -- NO OPEN-LOOP TRANSFER FUNCTIONS COMPUTED.
      OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
      OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
      OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
        SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
     NOISE TRANSFER FUNCTION OPTIONS:
        OPTION 1 -- NO NOISE TRANSFER FUNCTIONS COMPUTED.
        OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
        OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
        OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
        SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
     COMPENSATOR TRANSFER FUNCTION OPTIONS:
       OPTION 1 -- NO COMP. TRANSFER FUNCTIONS COMPUTED.
```

```
        OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
        OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
        OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
           (NOTE: A COMPENSATOR TRANSFER FUNCTION CAN BE
                  COMPUTED ONLY IF BOTH A REGULATOR
                  AND FILTER ARE SYNTHESIZED
                  AND/OR INPUT.)
          SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
     WILL A FEED-FORWARD DISTRIBUTION MATRIX
      "D" - MATRIX  BE INPUT ?

               TYPE "YES" OR "NO".
no
  THIS OPTION DETERMINES THE CRITERIA FOR DECIDING WHEN
  A MARKOV PARAMETER IS ZERO-THE MARKOV PARAMETER
  INDICATES THE ORDER OF THE NUMERATOR POLYNOMIAL OF EACH
  TRANSFER FUNCTION.
  ALL "N" ZEROS OF THIS POLYNOMIAL ARE PRINTED OUT AND
  THIS TEST TELLS HOW MANY EXTRA ROOTS EXIST AT Z = 0.
  LESS THAN 10.0**(-IE) IS CONSIDERED ZERO.
  THE DEFAULT VALUE OF THIS PARAMETER (IE) IS 6.
  IN OTHER WORDS, IE = 1.0E-6.
  IF YOU DESIRE A DIFFERENT MARKOV CRITERIA,
  TYPE THE INTEGER VALUE.
  IF YOU DESIRE THE DEFAULT VALUE, TYPE "0" (ZERO)
?
0
 DO YOU DESIRE TO SYNTHESIZE A STABLE FILTER (OR REGULATOR)
 BY DESTABILIZING THE ORIGINAL SYSTEM?
    (NOTE:WORKS FOR FILTER OR REGULATOR BUT NOT FOR BOTH
          IN THE SAME RUN.)
          TYPE "YES" OR "NO".
no
```

```
     DO YOU DESIRE TO PRINT THE EULER-LAGRANGE EIGENSYSTEM
        PRIOR TO DECOMPOSITION (FOR CHECKING THE PROGRAM)?
           TYPE "YES" OR "NO".
no
     POWER SPECTRAL DENSITY (PSD) OPTION 1 :
     OPTION 1 -- COMPUTE THE PSD OF THE OUTPUTS AND/OR
                 THE CONTROLS OF THE CONTROLLED SYSTEM
                 WHEN FORCED BY PROCESS AND MEASUREMENT
                 NOISE.  (NOTE: BOTH A REGULATOR AND A
                 FILTER MUST BE RESIDENT IN THE PROGRAM
                 TO USE THIS OPTION.)
     OPTION 2 -- SAME AS OPTION 1 ABOVE BUT ONLY PRINT THE
                 RESIDUES OF EACH TRANSFER FUNCTION
                 USED IN THE PSD COMPUTATION.
     OPTION 3 -- NOT DESIRED.
          SELECT AN OPTION: 1, 2, OR 3.
?
3
     DO YOU DESIRE REGULATOR SYNTHESIS ONLY?
          TYPE "YES" OR "NO".
no
     ENTER THE # OF STATES (NS) OF THE SYSTEM MATRIX
      "F"-MATRIX .
?
2
     ENTER THE # OF CONTROLS (NC) OF THE SYSTEM MODEL
      "G"-MATRIX .
?
1
     ENTER THE # OF MEASUREMENTS OR OBSERVATIONS (NO)
      "H"-MATRIX .
?
1
     ENTER THE # OF PROCESS NOISE SOURCES (NG)
      "GAMMA"-MATRIX .
```

```
?
0
    FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:
IOL   IQ   IR   ISS   IM   ITF1   ITF2   ITF3   IFDFW   IE   IDEBUG
 0     0    0    0     0    0      0      0      0       0    0
ISET   IDSTAB   IPSD   IYU   INORM   IREG   NS   NC   NOB   NG
  0      0        0     0      0       0     2    1    1    0

 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  1
 NUMBER OF PROCESS NOISE SOURCES =  0

     ENTER THE SYSTEM MATRIX  "F"-MATRIX
          DIMENSION = # STATES (NS) X # STATES (NS)
     THE ELEMENT F( 1, 1)=
?
0
     THE ELEMENT F( 1, 2)=
?
1
     THE ELEMENT F( 2, 1)=
?
0
     THE ELEMENT F( 2, 2)=
?
0
               THE SYSTEM MATRIX  "F"-MATRIX ...
     0.0          1.00000
     0.0          0.0
  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no

   OPEN LOOP DYNAMICS MATRIX..................F..
  0.0          0.1000D+01
```

```
  0.0          0.0

     ENTER THE MEASUREMENT SCALING MATRIX  "H"-MATRIX .
        DIMENSION = # OBSERVATIONS (NO) X # STATES (NS)
     THE ELEMENT H( 1, 1)=
?
1
     THE ELEMENT H( 1, 2)=
?
0
          THE MEASUREMENT SCALING MATRIX  "H"-MATRIX ...
     1.00000     0.0
   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
    MEASUREMENT SCALING MATRIX................H..
  0.1000E+01   0.0

     ENTER THE OUTPUT MEASUREMENT COST MATRIX  "A"-MATRIX .
     DIMENSION = # OBSERVATIONS (NO) X # OBSERVATIONS (NO)
     THE ELEMENT A( 1, 1)=
?
1
     THE OUTPUT MEASUREMENT COST MATRIX  "A"-MATRIX ...
     1.00000
   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
    OUTPUT COST MATRIX.........................A..
  0.1000E+01

     ENTER THE CONTROL DISTRIBUTION MATRIX  "G"-MATRIX .
          DIMENSION = # STATES (NS) X # CONTROLS (NC)
     THE ELEMENT G( 1, 1)=
?
0
```

```
      THE ELEMENT G( 2, 1)=
?
0
             THE CONTROL DISTRIBUTION MATRIX  "G"-MATRIX ...
      C.0
      0.0
    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
             TYPE "YES" OR "NO".
yes
      ENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.
?
2
      ENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED.
?
1
      THE ELEMENT G( 2, 1)=
?
1
             THE CONTROL DISTRIBUTION MATRIX  "G"-MATRIX ...
      C.0
      1.CC000
    DC YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
             TYPE "YES" OR "NO".
no
      ENTER THE CONTROL COST WEIGHTING MATRIX  "B"-MATRIX
             DIMENSION = # CONTROLS  NC  X # CONTROLS  NC
      THE ELEMENT B( 1, 1)=
1
?
             THE CONTROL COST MATRIX..........B...
      1.CC000
    DC YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
             TYPE "YES" OR "NO".
no
```

```
   THE CONTROL DISTRIBUTION MATRIX...........G..
 0.0
 0.1000D+01

   THE CONTROL COST MATRIX....................B..
 0.1000D+01

   EIGENSYSTEM OF OPTIMAL REGULATOR.........

   C-LOOP OPTIMAL REG. E-VALUES...DET(SI-F+G*C)..
-7.07107D-01, 7.07107D-01:

   C-LOOP RIGHT EIGENVECTOR MATRIX...........M....
-7.071068D-01 -7.071068D-01
 1.000000D+00  0.0

   CONTROL EIGENVECTOR MATRIX..............C*M..
  -7.071068D-01  7.071068D-01

   C-LOOP OPT. REG. LEFT E-VECTOR MATRIX..M-INV..
 0.0           1.000000D+00
-1.414214D+00 -1.000000D+00

 THE OPTIMAL FEEDBACK GAIN CONTROL MATRIX...C=BINV*GT*S...
 -1.0000D+00  -1.4142D+00

   THE CLOSED LOOP DYNAMICS MATRIX ......F-G*C..
 0.0           1.000000D+00
-1.000000D+00 -1.414214D+00

    ANALYSIS COMPLETE. DO YOU WANT ANOTHER RUN?
              TYPE "YES" OR "NO".
no
    ........OPTSYSX IS NOW TERMINATED........

R; T=0.54/2.84 15:36:49
record off
END RECORDING OF TERMINAL SESSION
```

D. EXAMPLE OF PROGRAM FAILURE

The following pathological example of program failure during regulator synthesis was taken from the Journal of Guidance and Control, Vol.3, No.2, pp.190-192, March-April 1980.

In this example, the choice of the quadratic index value was the factor promoting program instability; leading to eventual program failure in subroutine HQR2. The calculated regulator gains of -5.1, and -3.1 (pa. 63) are not correct!

With a 'slight' modification of the cost matrix from a previous value of 4.0000 to a new value of 4.0001, the program was run a second time. Failure did not occur on the second run, and the new calculations (pa. 68) indicate filter gains of -2.0, and a "small" residue of 3.19D-14 (essentially zero). These are the correct values.

This example points out one possible method of correcting certain program failure modes, should they occur during execution.

The full terminal session is recorded below, with user input in lower case letters following each "?" .

Following the program failure example, that portion of the repeated terminal output was deleted up to the point where program execution of the second run begins.

```
record on
BEGIN RECORDING OF TERMINAL SESSION
R; T=0.01/0.02 21:49:30
filedef 06 term (recfm fa blksize 133
global txtlib fortmod2 mod2eeh imsldp nonimsl
load optsysx (start

EXECUTION BEGINS...
 OPTSYSX IS A COMPLETELY INTERACTIVE OPTIMAL SYSTEMS CONTROL
    PROGRAM. IT WILL SOLVE NUMEROUS CONTROL PROBLEMS ON THE
          FOLLOWING TYPES OF SYSTEMS CONTROL EQUATIONS:
```

```
              XDOT =  (F)*X +  (G)*U +  (GAM)*(W+WO)
                  MEASUREMENT EQUATION--
                Z =  (H)*X +  (D)*W + V
                 REGULATOR PERFORMANCE INDEX--
               J = 1/2 * INTEGRAL  (Y *(A)*Y + U *(B)*U)DT
                 STATE FEEDBACK GAIN DEFINITION--
                         U = -(C)*X
             DO YOU WISH TO CONTINUE?  TYPE "YES" OR "NO".
yes
                         --DATA ENTRY--
     ALTHOUGH OPTSYSX IS SPECIFICALLY DESIGNED TO READ
     ALL MATRIX DATA INTERACTIVELY, SEVERAL ALTERNATE
     METHODS ARE AVAILABLE TO USERS:
       METHOD 1--THE "F","G", AND "GAMMA" MATRICES
             MAY BE READ FROM SEPARATE DATA FILES.
       METHOD 2--THE "F","G", AND "GAMMA" MATRICES MAY BE
             EXPLICITLY DEFINED WITHIN SUBROUTINE "SETUP".
       (NOTE: IN EITHER CASE, THE USER SHOULD OBTAIN A COPY
              OF THE PROGRAM LISTING AND EXAMINE
              THE EXAMPLES CONTAINED IN S/R "SETUP".)
        DO YOU WISH TO CONTINUE?  TYPE "YES" OR "NO".
yes
     DO YOU WISH TO INPUT THE "F", "G", AND "GAMMA"
          MATRICES FROM SUBROUTINE "SETUP" IAW THE
          METHOD DESCRIBED ON THE PREVIOUS SCREEN?
              TYPE "YES" OR "NO".
no
                    GENERAL OPTSYSX OPTIONS:
        OPTION 1 -- SYSTEM ANALYSIS WITHOUT
                    OPEN-LOOP EIGENSYSTEM CALCULATIONS.
        OPTION 2 -- SYSTEM ANALYSIS WITH OPEN-LOOP
                    EIGENSYSTEM CALCULATIONS.
        OPTION 3 -- OPEN-LOOP EIGENSYSTEM FOUND
                    AND PROGRAM TERMINATES.
              ("F"-MATRIX ENTRY FOLLOWS IMMEDIATELY.)
```

```
          OPTION 4 -- MODAL DISTRIBUTION MATRICES COMPUTED
                      WITHOUT FILTER OR REGULATOR SYNTHESIS
                      OF STEADY-STATE ANALYSIS.
                  SELECT AN OPTION: 1,2,3, OR 4.
?
2
     DO YOU DESIRE RMS VALUES OF STATE AND CONTROL?
          TYPE "YES" OR "NO".
yes
                      OPTSYSX LQR/CLASSICAL OPTIONS:
          OPTION 1 -- OPTIMAL FILTER AND/OR REGULATOR
                        SYNTHESIS WITH NO EXTERNAL "C" OR "K"
                        MATRIX INPUT.
          OPTION 2 -- OPTIMAL FILTER AND/OR REGULATOR
                        SYNTHESIS WITH EXTERNAL "C"
                        MATRIX INPUT.
          OPTION 3 -- OPTIMAL FILTER AND/OR REGULATOR
                        SYNTHESIS WITH EXTERNAL "K"
                        MATRIX INPUT.
          OPTION 4 -- OPTIMAL FILTER AND/OR REGULATOR
                        SYNTHESIS WITH EXTERNAL "C" AND "K"
                        MATRIX INPUT.
          SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
     DO YOU WISH TO DETERMINE THE STEADY-STATE RESPONSE
        FOR A CONSTANT DISTURBANCE?
          TYPE "YES" OR "NO".
no
     DO YOU WISH TO DETERMINE THE MODAL DISTRIBUTION
        AND GAIN MATRICES?
          TYPE "YES" OR "NO".
no
     OPEN-LOOP TRANSFER FUNCTION OPTIONS:
      OPTION 1 -- NO OPEN-LOOP TRANSFER FUNCTIONS COMPUTED.
```

```
      OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
      OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
      OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
          SELECT AN OPTION: 1, 2, 3, OR 4.
?
2
     NOISE TRANSFER FUNCTION OPTIONS:
          OPTION 1 -- NO NOISE TRANSFER FUNCTIONS COMPUTED.
          OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
          OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
          OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
          SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
     COMPENSATOR TRANSFER FUNCTION OPTIONS:
        OPTION 1 -- NO COMP. TRANSFER FUNCTIONS COMPUTED.
        OPTION 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.
        OPTION 3 -- ONLY POLES AND ZEROS COMPUTED.
        OPTION 4 -- ONLY POLES AND RESIDUES COMPUTED.
              (NOTE: A COMPENSATOR TRANSFER FUNCTION CAN BE
                     COMPUTED ONLY IF BOTH A REGULATOR
                     AND FILTER ARE SYNTHESIZED
                     AND/OR INPUT.)
          SELECT AN OPTION: 1, 2, 3, OR 4.
?
1
     WILL A FEED-FORWARD DISTRIBUTION MATRIX
     ("D" - MATRIX) BE INPUT ?
               TYPE "YES" OR "NO".
NO
DO YOU DESIRE TO SYNTHESIZE A STABLE FILTER (OR REGULATOR)
 BY DESTABILIZING THE ORIGINAL SYSTEM?

      (NOTE:WORKS FOR FILTER OR REGULATOR BUT NOT FOR BOTH
           IN THE SAME RUN.)
```

```
          TYPE "YES" OR "NO".
no
     DO YOU DESIRE TO PRINT THE EULER-LAGRANGE EIGENSYSTEM
        PRIOR TO DECOMPOSITION (FOR CHECKING THE PROGRAM)?
          TYPE "YES" OR "NO".
no
     POWER SPECTRAL DENSITY (PSD) OPTION 1 :
OPTION 1 -- COMPUTE THE PSD OF THE OUTPUTS AND/OR THE
            CONTROLS OF THE CONTROLLED SYSTEM WHEN FORCED BY
            PROCESS AND MEASUREMENT NOISE.  (NOTE: BOTH A
            REGULATOR AND A FILTER MUST BE RESIDENT IN THE
            PROGRAM TO USE THIS OPTION.)
OPTION 2 -- SAME AS OPTION 1 ABOVE BUT ONLY PRINT THE
            RESIDUES OF EACH TRANSFER FUNCTION
            USED IN THE PSD COMPUTATION.
OPTION 3 -- NOT DESIRED.
          SELECT AN OPTION: 1, 2, OR 3.
?
3
     DO YOU DESIRE REGULATOR SYNTHESIS ONLY?
          TYPE "YES" OR "NO".
yes
     ENTER THE # OF STATES (NS) OF THE SYSTEM MATRIX
     ("F"-MATRIX).
?
2
     ENTER THE # OF CONTROLS (NC) OF THE SYSTEM MODEL
     ("G"-MATRIX).
?
1
     ENTER THE # OF MEASUREMENTS OR OBSERVATIONS (NO)
     ("H"-MATRIX).
?
2
     ENTER THE # OF PROCESS NOISE SOURCES (NG)
```

```
     ("GAMMA"-MATRIX).
?
C
    FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:
IOL   IQ   IR   ISS   IM   ITF1   ITF2   ITF3   IFDFW   IE   IDEBUG
 1     1    C    0     0    1      0      0      0       0     0
ISET   IDSTAB  IPSD   IYU   INCRM   IREG   NS   NC   NOB   NG
  0      C       0     C      C       1     2    1    2    0

 ORDER CF SYSTEM =  2
 NUMBER CF CONTROLS =  1
 NUMBER CF CBSERVATICNS =  2
 NUMBER CF PROCESS NCISE SOURCES =  0

     ENTER THE SYSTEM MATRIX ("F"-MATRIX)
          DIMENSION = # STATES (NS) X # STATES (NS)
     THE ELEMENT F( 1, 1)=
?
C
     THE ELEMENT F( 1, 2)=
?
1
     THE ELEMENT F( 2, 1)=
?
-1
     THE ELEMENT F( 2, 2)=
?
0
                THE SYSTEM MATRIX ("F"-MATRIX)...

     0.0          1.0CC00
    -1.CC00C      0.0
     DO YCU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" CR "NO".
no
```

```
   OPEN LOOP DYNAMICS MATRIX..................F..
 0.0           0.1000D+01
-0.1000D+01    0.0

   OPEN LOOP EIGENVALUES...........DET(SI-F)..
0.0          , 1.00000D+00:

   OPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....
0.0            -1.000000D+00
1.000000D+00    0.0

   OPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..
0.0             1.000000D+00
-1.000000D+00   0.0

     ENTER THE MEASUREMENT SCALING MATRIX ("H"-MATRIX).
          DIMENSION = # OBSERVATIONS (NO) X # STATES (NS)
     THE ELEMENT H( 1, 1)=
?
0
     THE ELEMENT H( 1, 2)=
?
0
     THE ELEMENT H( 2, 1)=
?
0
     THE ELEMENT H( 2, 2)=
?
-1
          THE MEASUREMENT SCALING MATRIX ("H"-MATRIX)...
     0.0          0.0
     0.0         -1.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
```

```
    MEASUREMENT SCALING MATRIX................H..
  0.0          0.0
  0.0         -0.1000D+01

    MODAL MEASUREMENT SCALING MATRIX...H(BAR)*T..
    0.0            0.0
   -1.000000D+00   0.0

     ENTER THE OUTPUT MEASUREMENT COST MATRIX ("A"-MATRIX).
     DIMENSION = # OBSERVATIONS (NO) X # OBSERVATIONS (NO)
     THE ELEMENT A( 1, 1)=
?
0
     THE ELEMENT A( 1, 2)=
?
0
     THE ELEMENT A( 2, 1)=
?
0
     THE ELEMENT A( 2, 2)=
?
4
     THE OUTPUT MEASUREMENT COST MATRIX ("A"-MATRIX)...
     0.0          0.0
     0.0          4.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
    OUTPUT COST MATRIX........................A..
  0.0          0.0
  0.0          0.4000D+01

     ENTER THE CONTROL DISTRIBUTION MATRIX ("G"-MATRIX).
          DIMENSION = # STATES (NS) X # CONTROLS (NC)
     THE ELEMENT G( 1, 1)=
?
```

```
0
     THE ELEMENT G( 2, 1)=
?
1
          THE CONTROL DISTRIBUTION MATRIX ("G"-MATRIX)...
     0.0
     1.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
     ENTER THE CONTROL COST WEIGHTING MATRIX ("B"-MATRIX)
          DIMENSION = # CONTROLS (NC) X # CONTROLS (NC)
     THE ELEMENT B( 1, 1)=
?
1
          THE CONTROL COST MATRIX..........B...
     1.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
    THE CONTROL DISTRIBUTION MATRIX...........G..
  0.0
  0.1000D+01

    MODAL CONTROL DISTRIBUTION MATRIX......TI*G..
    1.0000000D+00
    0.0

    THE CONTROL COST MATRIX...................B..
  0.1000D+01
    OPEN LOOP TRANSFER FUNCTIONS...

TF FOR INPUT NO.  1 AND OUTPUT NO.  1:

    NO FINITE ZEROS.  TF GAIN =  0.0
```

```
  RESIDUES AT THE POLES:

      P O L E S                    R E S I D U E S
  REAL(A)       IMAG(B)
(  0.0   )+J( 1.000000) (   0.0 )    EXP(A*T)*COS(B*T)
(  0.0   )+J(-1.000000) (   0.0  )   EXP(A*T)*SIN(B*T)

TF FOR INPUT NO.  1 AND OUTPUT NO.  2:

  ORDER OF NUMERATOR =  1          TF GAIN = -0.1000D+01

  NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):
   (      0.0      )+J(      0.0       )
   (      0.0      )+J(      0.0       )

  RESIDUES AT THE POLES:

    P O L E S                   R E S I D U E S
 REAL(A)     IMAG(B)
( 0.0 )+J( 1.000000)   ( -1.000000)      EXP(A*T)*COS(B*T)
( 0.0 )+J(-1.000000)   (  0.0     )      EXP(A*T)*SIN(B*T)

   FAILURE IN HQR2 ON EIGENVALUE NO.    4

-1.962366D+00  3.464812D-03 -2.499867D+00  1.508857D+00
 3.464838D-03  3.762172D-02 -1.491143D+00  2.500102D+00
-4.415041D-15 -3.208843D-13 -1.962366D+00  3.621151D-03
 5.281945D-11 -1.267812D-17  3.621125D-03  3.762121D-02

    EIGENSYSTEM OF OPTIMAL REGULATOR.........

     EULER-LAGRANGE EQUATIONS HAVE A REAL EIGENVALUE
           AT OR NEAR ZERO.

    C-LOOP OPTIMAL REG. E-VALUES...DET(SI-F+G*C)..
 0.0         : 0.0         ,-1.00000D+00:

    C-LOOP RIGHT EIGENVECTOR MATRIX..........M....
-7.058807D-01  6.035185D-01
-7.083307D-01  1.000000D+00
```

```
    CCNTFCL EIGENVECTCR MATRIX..............C*M..
   -1.411761D+00 -1.504787D-02

    C-LCCP CPT. REG. LEFT E-VECTOR MATRIX..M-INV..
-3.592C82D+C0  2.167888D+00
-2.544382D+C0  2.535582D+00

 THE CPTIMAL FEEDBACK GAIN CCNTRCL MATRIX...C=BINV*GT*S...
  5.1C95D+0C  -3.0987D+00

    THE MCDAL CCNTRCL GAINS.................C*T..
   -3.C98696D+00 -5.1C9451D+C0

    TEE CLCSED LCCP DYNAMICS MATRIX ......F-G*C..
 0.0            1.000CCCD+00
 4.1C9451D+C0 -3.098696D+00

     ANALYSIS COMPLETE. DO YOU WANT ANOTHER RUN?
               TYPE "YES" OR "NO".
yes
     DO YOU WISH TO SAVE THE "F"-MATRIX FROM THE LAST
     RUN TO BE USED IN THE FOLLOWING RUN?
     NCTE: THE MATRIX WILL EE REDISPLAYED AT
     TEE PRCPER INPUT SEQUENCE INTERVAL
     AND YCU WILL HAVE THE CPTION OF CHANGING
     INDIVIDUAL MATRIX ELEMENTS.
               TYPE "YES" OR "NC".
yes
     DO YOU WISH TO SAVE THE "H"-MATRIX FRCM THE LAST
     RUN TO BE USED IN THE FOLLOWING RUN?
     NCTE: THE MATRIX WILL EE REDISPLAYED AT
     TEE PRCPER INPUT SEQUENCE INTERVAL
     AND YCU WILL HAVE THE CPTION OF CHANGING
     INDIVIDUAL MATRIX ELEMENTS.
               TYPE "YES" OR "NC".
yes
     DC YOU WISH TO SAVE THE "G"-MATRIX FROM THE LAST
```

```
     RUN TO BE USED IN THE FOLLOWING RUN?
     NOTE: THE MATRIX WILL BE REDISPLAYED AT
     THE PROPER INPUT SEQUENCE INTERVAL
     AND YOU WILL HAVE THE OPTION OF CHANGING
     INDIVIDUAL MATRIX ELEMENTS.
              TYPE "YES" OR "NO".
yes
```

Author's note: Since the same program options are to be run again, with only a change in one of the cost matrix element values, the terminal output was deleted up to the point where program calculations resume in order to avoid redundancy.

```
 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  2
 NUMBER OF PROCESS NOISE SOURCES =  0

              THE SYSTEM MATRIX ("F"-MATRIX)...
     0.0          1.00000
    -1.00000      0.0

     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
    OPEN LOOP DYNAMICS MATRIX.................F..
  0.0            0.1000D+01
 -0.1000D+01     0.0

    OPEN LOOP EIGENVALUES..........DET(SI-F)..
 0.0           , 1.00000D+00:

    OPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....
 0.0            -1.000000D+00
 1.000000D+00   0.0
```

```
    CPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..
 0.0              1.000000D+00
-1.000000D+00   0.0

          THE MEASUREMENT SCALING MATRIX ("H"-MATRIX)...
     0.0          0.0
     0.0         -1.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
    MEASUREMENT SCALING MATRIX................H..
  0.0           0.0
  0.0          -0.1000D+01

    MODAL MEASUREMENT SCALING MATRIX...H(BAR)*T..
    0.0            0.0
   -1.000000D+00  0.0

     ENTER THE OUTPUT MEASUREMENT COST MATRIX ("A"-MATRIX).
     DIMENSION = # OBSERVATIONS (NO) X # OBSERVATIONS (NO)
     THE ELEMENT A(  1,  1)=
?
0
     THE ELEMENT A(  1,  2)=
?
0
     THE ELEMENT A(  2,  1)=
?
0
     THE ELEMENT A(  2,  2)=
?
4.0001
     THE OUTPUT MEASUREMENT COST MATRIX ("A"-MATRIX)...
     0.0          0.0
     0.0          4.00010
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
```

```
          TYPE "YES" OR "NO".
no
    OUTPUT COST MATRIX.........................A..
  0.0            0.0
  0.0            0.4000D+01

          THE CONTROL DISTRIBUTION MATRIX ("G"-MATRIX)...
     0.0
     1.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
     ENTER THE CONTROL COST WEIGHTING MATRIX ("B"-MATRIX)
          DIMENSION = # CONTROLS (NC) X # CONTROLS (NC)
     THE ELEMENT B( 1, 1)=
?
1
          THE CONTROL COST MATRIX..........B...
     1.00000
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
no
    THE CONTROL DISTRIBUTION MATRIX...........G..
  0.0
  0.1000D+01

    MODAL CONTROL DISTRIBUTION MATRIX......TI*G..
    1.000000D+00
    0.0

    THE CONTROL COST MATRIX..................B..
  0.1000D+01

    OPEN LOOP TRANSFER FUNCTIONS...

TF FOR INPUT NO.  1 AND OUTPUT NO.  1:

    NO FINITE ZEROS.  TF GAIN =  0.0
```

```
  RESIDUES AT THE POLES:
        P O L E S                    R E S I D U E S
  REAL(A)      IMAG(B)
(  0.0   )+J(  1.000000)    (  0.0  )    EXP(A*T)*COS(B*T)
(  0.0   )+J( -1.000000)    (  0.0  )    EXP(A*T)*SIN(B*T)

TF FOR INPUT NO.  1 AND OUTPUT NO.  2:

  ORDER OF NUMERATOR =  1          TF GAIN = -0.1000D+01

  NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):
   (      0.0      )+J(      0.0      )
   (      0.0      )+J(      0.0      )

  RESIDUES AT THE POLES:
         P O L E S                    R E S I D U E S
   REAL(A)        IMAG(B)
(  0.0   )+J(  1.000000)     ( -1.000000)     EXP(A*T)*COS(B*T)
(  0.0   )+J( -1.000000)     (  0.0     )     EXP(A*T)*SIN(B*T)



    EIGENSYSTEM OF OPTIMAL REGULATOR.........

    C-LOOP OPTIMAL REG. E-VALUES...DET(SI-F+G*C)..
-1.005010D+00:-9.950120D-01:

    C-LOOP RIGHT EIGENVECTOR MATRIX..........M....
 7.053368D-01 -7.088723D-01
-7.088723D-01  7.053368D-01

    CONTROL EIGENVECTOR MATRIX..............C*M..
    1.417762D+00 -1.410691D+00

    C-LOOP OPT. REG. LEFT E-VECTOR MATRIX..M-INV..
-1.410691D+02 -1.417762D+02
-1.417762D+02 -1.410691D+02
```

```
 THE OPTIMAL FEEDBACK GAIN CONTROL MATRIX...C=BINV*GT*S...
 -3.1974D-14  -2.0000D+00

    THE MODAL CONTROL GAINS..................C*T..
   -2.000025D+00  3.197442D-14

    THE CLOSED LOOP DYNAMICS MATRIX ......F-G*C..
 0.0            1.000000D+00
-1.000000D+00 -2.000025D+00

      ANALYSIS COMPLETE. DO YOU WANT ANOTHER RUN?
                TYPE "YES" OR "NO".
no

    .......OPTSYSX IS NOW TERMINATED........
R; T=0.63/2.60 23:33:07
record off
END RECORDING OF TERMINAL SESSION
```

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Although originally developed for the quadratic synthesis of controllers for rotary-wing VTOL aircraft, the extensive modifications and enhancements of Hall's original work, coupled with its efficient and accurate eigensystem solution routine, represent a powerful tool in the design of optimally controlled systems.

In its present interactive form, OPTSYSX has been transferred from the arena of high-level applied mathematics and numerical analysis to the level of control system engineers and students. It now represents an even more powerful educational tool, able to rapidly and effectively unlock many misunderstood linear systems mathematical relationships.

As an ultimate evaluation of the computational abilities of OPTSYSX, the program was tested using an 82 X 82 matrix of aircraft longitudinal motion equations for the VX-29 experimental Fighter aircraft derivative, provided by NASA-Edwards.

For a system of equations of this magnitude, all program arrays were re-dimensioned (as shown in Appendix A), and a 2-Megabyte virtual machine size was required. This system was run through the Modal Analysis option of OPTSYSX, requiring less than 90 seconds to load the system and complete all open-loop and modal analysis calculations!

Program results exhibited perfect eigenvalue correlation with those obtained from the John Edwards Control Program. Additionally, OPTSYSX provided complete longitudinal modal analysis, previously unavailable on a system of this size.

It is hoped that the use of this interactive program version will be encouraged; and that its expanded abilities will stimulate both interest in and research on basic systems control problems, as well as more advanced designs.

E. RECOMMENDATIONS

Based on the results of this thesis, four areas emerged as possibilities for further research and study:

1. Program Availability

The use of OPTSYSX and similar design programs should be encouraged in all undergraduate and graduate level courses involved in the analysis and design of control systems. Toward this end, it is recommended that OPTSYSX be placed in the non-IMSL library of subroutines, making it easily available to all potential users.

2. Computer Graphics

The addition of graphical plotting routines to the program in the time and frequency domain would make OPTSYSX an even more powerful tool in the design of many optimally controlled systems.

3. Further Modifications

The present version of the program should be modified to include the OPTSYS 5 derivative input term improvements of Liu [Ref. 3], and program sequencing during optimal filter synthesis should be examined. Various test runs indicate an area of conflict in that the program appears to require the design of an optimal regulator prior to performing any filter calculations.

4. Program Application

CPTSYSX offers attractive possibilities in the area of microcomputer implementation.

APPENDIX A

OPTSYSX PROGRAM LISTING

```
C************************************************************************
C************************************************************************
C*************                                              *************
C***********                 OPTSYSX                          ***********
C*********               BY JOHN G. HODEN                       *********
C*********                                                      *********
C*********     THIS PROGRAM IS A COMPLETELY INTERACTIVE         *********
C*********     OPTIMAL SYSTEMS CONTROL DESIGN/SYNTHESIS         *********
C*********     PROGRAM CAPABLE OF HANDLING VERY LARGE (80X80)+  *********
C*********     MULTIVARIABLE SYSTEMS OF LINEAR EQUATIONS.       *********
C*********                                                      *********
C***********          VERSION 1.8    11 MAR 1984              ***********
C*************                                              *************
C************************************************************************
C************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
C-----------------------------------------------------------------------
      INTEGER IANS,ICL,IQ,IR,ISS,IM,ITP1,ITP2,ITP3,IPDFW,IE,IDEBUG,ISET,
     1IPSD,IYU,INORM,NS,NC,NOB,NG,IBEG,IDSTAB,IRET,NROW,NCOL,ISAF,ISAH,I
     2SAG,IGAM
C-----------------------------------------------------------------------
C     LARGE ORDER SYSTEM (82 X 82) DIMENSIONS.
C-----------------------------------------------------------------------
C     DIMENSION ACL(82,82),B(41,41),EA(82,82),CI(82),CR(82),CQ(82,82),
C    *CWI(82),CWR(82),FBGC(41,82),FBGE(82,41),G(82,82),GM(82,82),
C    *PRO(82,82),RC(41,41),SC(82,82),WR(164),WI(164),W11(82,82),
C    *W21(82,82),X(164,164),GN(82,82),HO(41,82),D1(164),D2(164),
C    *RM(164,164),Q(41,41),GAM(82,41),WNORM(82,82),WNORMI(82,82),
C    *DESTAB(82),AA(82,82),BM(82,41),CM(41,82),D(41,41),DSTORE(82,82),
C    *JCP(164),RES(164),AY(82,82),BB(164),CC(164),CP(82),GW(164,41),
C    *GV(164,41),HY(41,164),HU(41,164),PRTT(16,16),DUM(82,85)
C-----------------------------------------------------------------------
C     STANDARD PROGRAM DIMENSIONS.
C-----------------------------------------------------------------------
      DIMENSION ACL(32,32),B(32,32),EA(32,32),CI(32),CR(32),CQ(32,32),CW
     1I(32),CWR(32),FBGC(32,32),FBGE(32,32),G(32,32),GM(32,32),PRO(32,32
     2),RC(32,32),SC(32,32),WR(64),WI(64),W11(32,32),W21(32,32),X(64,64)
     3,GN(32,32),HO(32,32),D1(64),D2(64),RM(64,64),Q(32,32),GAM(32,32),W
     4NORM(32,32),WNORMI(32,32),DESTAB(32),AA(32,32),BM(32,32),CM(32,32)
     5,D(32,32),DSTORE(32,32),JCP(64),RES(64),AY(32,32),BB(64),CC(64),CP
     6(32),GW(64,64),GV(64,64),HY(64,64),HU(64,64),PRTT(16,16),DUM(32,32
     7)
C-----------------------------------------------------------------------
      EQUIVALENCE (W11(1,1),GW(1,1)), (W11(1,1),GV(1,1)), (W21(1,1),HY(1
     1,1)), (W21(1,1),HU(1,1))
C-----------------------------------------------------------------------
      COMMON /PROG/ IOL,IQ,IR,ISS,IM,ITP1,ITP2,ITP3,IPDFW,IE,IDSTAB,IDEB
     1UG,ISET,IBEG,IPSD,IYU,INORM
C-----------------------------------------------------------------------
      DATA IY/'Y'/,IZ/'N'/
C-----------------------------------------------------------------------
C  SUPPRESS INDIVIDUAL UNDERFLOW, OVERFLOW, DIVIDE CHECK, AND DECIMAL  =
C  CONVERT ERROR MESSAGES; PROVIDE SUMMARY OF ERRORS ONLY.             =
C-----------------------------------------------------------------------
      CALL ERRSET (207,256,-1,1,1,209)
      CALL ERRSET (215,256,-1,1)
C-----------------------------------------------------------------------
C  INITIALIZE FLAGS.                                                   =
C-----------------------------------------------------------------------
      ISAF=0
      ISAG=0
      ISAH=0
      IGAM=0
10    CONTINUE
      IRET=0
      ICL=0
      IQ=0
      IR=0
      ISS=0
      IM=0
      ITP1=0
      ITP2=0
      ITP3=0
      IPDFW=0
      IE=0
      IDSTAB=0
```

```
      IDEBUG=0
      ISET=0
      IPSD=0
      IYU=0
      INORM=0
      IBEG=0
      NS=0
      NC=0
      NCB=0
      NG=0
C--------------------------------------------------------SCRN1-----------------
20    CALL PRTCMS ('CLRSCRN ')
      WRITE (5,890)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 30
      GO TO 40
30    WRITE (5,880)
      GO TO 20
40    CONTINUE
      IF (IANS.EQ.IZ) GO TO 560
C--------------------------------------------------------SCRN2-----------------
50    CALL PRTCMS ('CLRSCRN ')
      WRITE (5,900)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 60
      GO TO 70
60    WRITE (5,880)
      GO TO 50
70    CONTINUE
      IF (IANS.EQ.IZ) GO TO 560
C--------------------------------------------------------ISET------------------
80    CALL PRTCMS ('CLRSCRN ')
      WRITE (5,910)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 90
      GO TO 100
90    WRITE (5,880)
      GO TO 80
100   CONTINUE
      IF (IANS.EQ.IY) ISET=1
C--------------------------------------------------------IOL-------------------
      CALL PRTCMS ('CLRSCRN ')
      WRITE (5,570)
      CALL RDINT (IANS)
      IOL=IANS-1
      IF (IOL.EQ.2) GO TO 350
C--------------------------------------------------------IQ--------------------
      CALL PRTCMS ('CLRSCRN ')
110   WRITE (5,580)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 120
      GO TO 130
120   WRITE (5,880)
      GO TO 110
130   CONTINUE
      IF (IANS.EQ.IY) IQ=1
      IF (IANS.EQ.IZ) IQ=0
      IF (IOL.EQ.3) GO TO 200
C--------------------------------------------------------IR--------------------
      CALL PRTCMS ('CLRSCRN ')
      WRITE (5,590)
      CALL RDINT (IANS)
      IR=IANS-1
C--------------------------------------------------------ISS-------------------
      CALL PRTCMS ('CLRSCRN ')
140   WRITE (5,600)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 150
      GO TO 160
150   WRITE (5,880)
      GO TO 140
160   CONTINUE
      IF (IANS.EQ.IY) ISS=1
      IF (IANS.EQ.IZ) ISS=0
C--------------------------------------------------------IM--------------------
170   WRITE (5,610)
```

```
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 180
      GO TO 190
180   WRITE (5,880)
      GO TO 170
190   CONTINUE
      IF (IANS.EQ.IY) IM=1
      IF (IANS.EQ.IZ) IM=0
200   CONTINUE
      IF (IOL.EQ.3) IM=1
C------------------------------------------------------------ITF1------------------
      CALL FRTCMS ('CLRSCRN ')
      WRITE (5,620)
      CALL RDINT (IANS)
      ITF1=IANS-1
C     IF (IOL.EQ.3) GO TO 240
C------------------------------------------------------------ITF2------------------
      CALL FRTCMS ('CLRSCRN ')
      WRITE (5,630)
      CALL RDINT (IANS)
      ITF2=IANS-1
C     IF (IOL.EQ.3) GO TO 240
C------------------------------------------------------------ITF3------------------
      CALL FRTCMS ('CLRSCRN ')
      WRITE (5,640)
      CALL RDINT (IANS)
      ITF3=IANS-1
C------------------------------------------------------------IFDFW-----------------
      CALL FRTCMS ('CLRSCRN ')
210   WRITE (5,650)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 220
      GO TO 230
220   WRITE (5,880)
      GO TO 210
230   CONTINUE
      IF (IANS.EQ.IY) IFDFW=1
      IF (IANS.EQ.IZ) IFDFW=0
C------------------------------------------------------------IE--------------------
      CALL FRTCMS ('CLRSCRN ')
      WRITE (5,660)
      CALL RDREAL (ANSR)
      IE=IDINT(ANSR)
      IF (IOL.EQ.3) GO TO 300
C------------------------------------------------------------IDSTAB----------------
      CALL FRTCMS ('CLRSCRN ')
240   WRITE (5,670)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 250
      GO TO 260
250   WRITE (5,880)
      GO TO 240
260   CONTINUE
      IF (IANS.EQ.IY) IDSTAB=1
      IF (IANS.EQ.IZ) IDSTAB=0
C------------------------------------------------------------IDEBUG----------------
270   WRITE (5,680)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 280
      GO TO 290
280   WRITE (5,880)
      GO TO 270
290   CONTINUE
      IF (IANS.EQ.IY) IDEBUG=1
      IF (IANS.EQ.IZ) IDEBUG=0
300   CONTINUE
C------------------------------------------------------------IPSD------------------
      CALL FRTCMS ('CLRSCRN ')
      WRITE (5,690)
      CALL RDINT (IANS)
      IPSD=IANS
      IF (IPSD.EQ.3) IPSD=0
      IF (IPSD.EQ.0) GO TO 310
C------------------------------------------------------------IYU-------------------
      CALL FRTCMS ('CLRSCRN ')
      WRITE (5,700)
```

```
      CALL RDINT (IANS)
      IYU=IANS-1
C-----------------------------------------------------------INORM-----------------
      CALL PRTCMS ('CLRSCRN ')
      WRITE (5,820)
      CALL RDREAL (ANSR)
      INORM=IDINT(ANSR)
310   IF (IOL.EQ.3) GO TO 350
C-----------------------------------------------------------IREG------------------
      CALL PRTCMS ('CLRSCRN ')
320   WRITE (5,710)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 330
      GO TO 340
330   WRITE (5,880)
      GO TO 320
340   CONTINUE
      IF (IANS.EQ.IY) IREG=1
      IF (IANS.EQ.IZ) IREG=0
C-----------------------------------------------------------NS--------------------
350   CALL PRTCMS ('CLRSCRN ')
      WRITE (5,720)
      CALL RDREAL (ANSR)
      NS=IDINT(ANSR)
      IF (IOL.EQ.2) GO TO 360
C-----------------------------------------------------------NC--------------------
      WRITE (5,730)
      CALL RDREAL (ANSR)
      NC=IDINT(ANSR)
C-----------------------------------------------------------NOB-------------------
      WRITE (5,740)
      CALL RDREAL (ANSR)
      NOB=IDINT(ANSR)
C-----------------------------------------------------------NG--------------------
      WRITE (5,750)
      CALL RDREAL (ANSR)
      NG=IDINT(ANSR)    '
360   CONTINUE
C-----------------------------------------------------------FLAG SETTINGS---------
      CALL PRTCMS ('CLRSCRN ')
      WRITE (6,760)
      WRITE (6,770)
      WRITE (6,780)  IOL,IQ,IR,ISS,IP,ITF1,ITF2,ITF3,IFDFW,IE,IDEBUG,ISET
     1,IDSTAB
      WRITE (6,790)
      WRITE (6,800)  IPSD,IYU,INORM,IREG,NS,NC,NOB,NG
      WRITE (6,810)  NS,NC,NOB,NG
C-----------------------------------------------------------BEGIN CALCULATIONS-----
      N2=2*NS
      CALL INNER (NS,NC,NOB,NG,N2,ACL,B,BA,CI,CR,CQ,CWI,CWR,D,FBGC,FBGE,
     1G,GAM,GM,GN,HC,D1,D2,PRO,RM,RC,Q,SC,WR,WI,W11,W21,X,WNORM,WNORMI,D
     2ESTAB,AA,BM,CM,JCF,RES,AY,BB,CC,CP,GW,GV,HY,HU,DSTORE,ISAF,ISAH,IS
     3AG,IGAM,IRET,PRTT,NROW,NCOL)
C-----------------------------------------------------------IRET------------------
370   WRITE (5,830)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 380
      GO TO 390
380   WRITE (5,880)
      GO TO 370
390   CONTINUE
      IF (IANS.EQ.IY) GO TO 400
      IF (IANS.EQ.IZ) GO TO 560
C-----------------------------------------------------------ISAF------------------
400   CONTINUE
      IF (IRET.EQ.1) GO TO 10
      IF (ISET.EQ.1) GO TO 10
      CALL PRTCMS ('CLRSCRN ')
410   WRITE (5,840)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 420
      GO TO 430
420   WRITE (5,880)
      GO TO 410
430   CONTINUE
      IF (IANS.EQ.IY) ISAF=1
```

```
      IF (IANS.EQ.IZ) ISAF=0
C-----------------------------------------------------------ISAH------------------
      IF (NOB.EQ.0) GO TO 470
      CALL FRTCMS ('CLRSCRN ')
440   WRITE (5,850)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 450
      GO TO 460
450   WRITE (5,880)
      GO TO 440
460   CONTINUE
      IF (IANS.EQ.IY) ISAH=1
      IF (IANS.EQ.IZ) ISAH=0
470   CONTINUE
C-----------------------------------------------------------ISAG------------------
      IF (NC.EQ.0) GO TO 510
      CALL FRTCMS ('CLRSCRN ')
480   WRITE (5,860)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 490
      GO TO 500
490   WRITE (5,880)
      GO TO 480
500   CONTINUE
      IF (IANS.EQ.IY) ISAG=1
      IF (IANS.EQ.IZ) ISAG=0
510   CONTINUE
C-----------------------------------------------------------IGAM------------------
      IF (NG.EQ.0) GO TO 550
      CALL FRTCMS ('CLRSCRN ')
520   WRITE (5,870)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 530
      GO TO 540
530   WRITE (5,880)
      GO TO 520
540   CONTINUE
      IF (IANS.EQ.IY) IGAM=1
      IF (IANS.EQ.IZ) IGAM=0
550   CONTINUE
      GO TO 10
C-----------------------------------------------------------TERMINATE-------------
560   WRITE (5,920)
      STOP
C---------------------------------------------------------------------------------
570   FORMAT (25X,24HGENERAL OPTSYSX OPTIONS:,//,10X,35HOPTION 1 -- SYST
     1EM ANALYSIS WITHOUT,/,22X,35HOPEN-LOOP EIGENSYSTEM CALCULATIONS.,/
     2/,10X,42HOPTION 2 -- SYSTEM ANALYSIS WITH OPEN-LOOP,/,22X,25HEIGEN
     3SYSTEM CALCULATIONS.,//,10X,39HOPTION 3 -- OPEN-LOOP EIGENSYSTEM F
     4OUND,/,22X,23HAND PROGRAM TERMINATES.,/,22X,39H "F"-MATRIX ENTRY F
     5OLLOWS IMMEDIATELY. ,//,10X,48HOPTION 4 -- MODAL DISTRIBUTION MATR
     6ICES COMPUTED,/,22X,37HWITHOUT FILTER OR REGULATOR SYNTHESIS,/,22X
     7,25HOR STEADY-STATE ANALYSIS.,//,15X,30HSELECT AN OPTION: 1,2,3, O
     8R 4.)
580   FORMAT (//,5X,46HDO YOU DESIRE RMS VALUES OF STATE AND CONTROL?,//
     1,10X,19HTYPE "YES" OR "NO".)
590   FORMAT (/,20X,30HOPTSYSX LQR/CLASSICAL OPTIONS:,//,10X,43HOPTION 1
     1 -- OPTIMAL FILTER AND/OR REGULATOR,/,22X,37HSYNTHESIS WITH NO EXT
     2ERNAL "C" OR "K",/,22X,13HMATRIX INPUT.,//,10X,43HOPTION 2 -- OPTI
     3MAL FILTER AND/OR REGULATOR,/,22X,27HSYNTHESIS WITH EXTERNAL "C",/
     4,22X,13HMATRIX INPUT.,//,10X,43HOPTION 3 -- OPTIMAL FILTER AND/OR
     5REGULATOR,/,22X,27HSYNTHESIS WITH EXTERNAL "K",/,22X,13HMATRIX INP
     6UT.,//,10X,43HOPTION 4 -- OPTIMAL FILTER AND/OR REGULATOR,/,22X,35
     7HSYNTHESIS WITH EXTERNAL "C" AND "K",/,22X,13HMATRIX INPUT.,//,10X
     8,32HSELECT AN OPTION: 1, 2, 3, OR 4.)
600   FORMAT (//,5X,50HDO YOU WISH TO DETERMINE THE STEADY-STATE RESPONS
     1E,/,8X,27HFOR A CONSTANT DISTURBANCE?,//,10X,19HTYPE "YES" OR "NO"
     2.)
610   FORMAT (5X,47HDO YOU WISH TO DETERMINE THE MODAL DISTRIBUTION,/,8X
     1,18HAND GAIN MATRICES?,//,10X,19HTYPE "YES" OR "NO".)
620   FORMAT (//,5X,36HOPEN-LOOP TRANSFER FUNCTION OPTIONS:,//,10X,53HOP
     1TION 1 -- NO OPEN-LOOP TRANSFER FUNCTIONS COMPUTED.,//,10X,48HOPTI
     2ON 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.,//,10X,42HOPTION 3 --
     3 ONLY POLES AND ZEROS COMPUTED.,//,10X,45HOPTION 4 -- ONLY POLES A
     4ND RESIDUES COMPUTED.,//,10X,32HSELECT AN OPTION: 1, 2, 3, OR 4.)
630   FORMAT (//,5X,32HNOISE TRANSFER FUNCTION OPTIONS:,//,10X,49HOPTION
```

```
     1 1 -- NO NOISE TRANSFER FUNCTIONS COMPUTED.,//,10X,48HOPTION 2 --
     2POLES, RESIDUES, AND ZEROS COMPUTED.,//,10X,42HOPTION 3 -- ONLY PO
     3LES AND ZEROS COMPUTED.,//,10X,45HOPTION 4 -- ONLY POLES AND RESID
     4UES COMPUTED.,//,10X,32HSELECT AN OPTION: 1, 2, 3, OR 4.)
640   FORMAT (//,5X,38HCOMPENSATOR TRANSFER FUNCTION OPTIONS:,//,10X,49H
     1OPTION 1 -- NO COMP. TRANSFER FUNCTIONS COMPUTED.,//,10X,48HOPTION
     2 2 -- POLES, RESIDUES, AND ZEROS COMPUTED.,//,10X,42HOPTION 3 -- O
     3NLY POLES AND ZEROS COMPUTED.,//,10X,45HOPTION 4 -- ONLY POLES AND
     4 RESIDUES COMPUTED.,//,15X,45H NOTE: A COMPENSATOR TRANSFER FUNCTI
     5ON CAN BE,/,22X,33HCOMPUTED ONLY IF BOTH A REGULATOR,/,22X,26HAND
     6FILTER ARE SYNTHESIZED,/,22X,14HAND/OR INPUT. ,//,10X,32HSELECT AN
     7 OPTION: 1, 2, 3, OR 4.)
650   FORMAT (//,5X,39HWILL A FEED-FORWARD DISTRIBUTION MATRIX,/,5X,25H
     1"D" - MATRIX  BE INPUT ?,//,15X,19HTYPE "YES" OR "NO".)
660   FORMAT (/,5X,63H THIS OPTION DETERMINES THE CRITERIA FOR DECIDING
     1WHEN A MARKOV,/,8X,58HPARAMETER IS ZERO-THE MARKOV PARAMETER INDIC
     2ATES THE ORDER,/,8X,54HOF THE NUMERATOR POLYNOMIAL OF EACH TRANSFE
     3R FUNCTION.,//,8X,52HALL "N" ZEROS OF THIS POLYNOMIAL ARE PRINTED
     4OUT AND,/,8X,52HTHIS TEST TELLS HOW MANY EXTRA ROOTS EXIST AT Z =
     50.,/,8X,41HLESS THAN 10.0** -IE  IS CONSIDERED ZERO.,//,8X,47H THE
     6 DEFAULT VALUE OF THIS PARAMETER  IE  IS 6.,/,8X,28HIN OTHER WORDS
     7, IE = 1.0E-6.,//,10X,66HIF YOU DESIRE A DIFFERENT MARKOV CRITERIA
     8, TYPE THE INTEGER VALUE.,//,10X,48HIF YOU DESIRE THE DEFAULT VALU
     9E, TYPE "0"  ZERO )
670   FORMAT (//,5X,61HDO YOU DESIRE TO SYNTHESIZE A STABLE FILTER  OR R
     1EGULATOR  BY,/,8X,34HDESTABILIZING THE ORIGINAL SYSTEM?,//,12X,52H
     2 NOTE:WORKS FOR FILTER OR REGULATOR BUT NOT FOR BOTH,/,20X,17HIN T
     3HE SAME RUN. ,//,10X,19HTYPE "YES" OR "NO".)
680   FORMAT (5X,53HDO YOU DESIRE TO PRINT THE EULER-LAGRANGE EIGENSYSTE
     1M,/,8X,50HPRIOR TO DECOMPOSITION  FOR CHECKING THE PROGRAM ?,//,10
     2X,19HTYPE "YES" OR "NO".)
690   FORMAT (//,5X,39HPOWER SPECTRAL DENSITY  PSD  OPTION 1 :,//,10X,53
     1HOPTION 1 -- COMPUTE THE PSD OF THE OUTPUTS AND/OR THE,/,22X,48HCO
     2NTROLS OF THE CONTROLLED SYSTEM WHEN FORCED BY,/,22X,45HPROCESS AN
     3D MEASUREMENT NOISE.   NOTE: BOTH A,/,22X,46HREGULATOR AND A FILTE
     4R MUST BE RESIDENT IN THE,/,22X,28HPROGRAM TO USE THIS OPTION. ,//
     5,10X,53HOPTION 2 -- SAME AS OPTION 1 ABOVE BUT ONLY PRINT THE,/,22
     6X,34HRESIDUES OF EACH TRANSFER FUNCTION,/,22X,28HUSED IN THE PSD C
     7OMPUTATION.,//,10X,24HOPTION 3 -- NOT DESIRED.,///,10X,29HSELECT A
     8N OPTION: 1, 2, OR 3.)
700   FORMAT (//,5X,39HPOWER SPECTRAL DENSITY  PSD  OPTION 2 :,//,10X,35
     1HOPTION 1 -- PSD OUTPUT NOT DESIRED.,//,10X,38HOPTION 2 -- COMPUTE
     2 ONLY OUTPUT PSD°S.,//,10X,39HOPTION 3 -- COMPUTE ONLY CONTROL PSD
     3°S.,//,10X,50HOPTION 4 -- COMPUTE BOTH OUTPUT AND CONTROL PSD°S.,/
     4/,15X,32HSELECT AN OPTION: 1, 2, 3, OR 4.)
710   FORMAT (//,5X,39HDO YOU DESIRE REGULATOR SYNTHESIS ONLY?,//,10X,19
     1HTYPE "YES" OR "NO".,//)
720   FORMAT (/,5X,47HENTER THE # OF STATES  NS  OF THE SYSTEM MATRIX,/,
     15X,13H "F"-MATRIX .)
730   FORMAT (/,5X,56HENTER THE # OF CONTROLS  NC  OF THE CONTROL SYSTEM
     1 MODEL,/,5X,13H "G"-MATRIX .)
740   FORMAT (/,5X,54HENTER THE # OF MEASUREMENTS OR OBSERVATIONS  NO  O
     1F THE,/,5X,13H "H"-MATRIX .)
750   FORMAT (/,5X,48HENTER THE # OF PROCESS NOISE SOURCES  NG  OF THE,/
     1,5X,17H "GAMMA"-MATRIX .)
760   FORMAT (5X,52HFLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:
     1,/)
770   FORMAT (1X,3HIOL,2X,2HIQ,2X,2HIR,2X,3HISS,2X,2HIM,2X,4HITF1,2X,4HI
     1TF2,2X,4HITF3,2X,5HIFDFW,2X,2HIE,2X,6HIDEBUG,2X,4HISET,2X,6HIDSTAB
     2,/)
780   FORMAT (1X,I2,3X,I2,3X,I2,2X,I2,3X,I2,3X,I2,4X,I2,4X,I2,4X,I2,4X,I
     12,3X,I2,6X,I2,5X,I2,/)
790   FORMAT (1X,4HIPSD,2X,3HIYU,2X,5HINORM,2X,4HIREG,2X,2HNS,2X,2HNC,2X
     1,3HNOB,2X,2HNG,/)
800   FORMAT (2X,I2,3X,I2,4X,I2,5X,I2,3X,I2,2X,I2,3X,I2,2X,I2,//)
810   FORMAT (2X,17HORDER OF SYSTEM =,I3,//,2X,20HNUMBER OF CONTROLS =,I
     13,//,2X,24HNUMBER OF OBSERVATIONS =,I3,//,2X,33HNUMBER OF PROCESS
     2NOISE SOURCES =,I3,////)
820   FORMAT (5X,53HDETERMINE THE NORMALIZATION PARAMETER  INORM  FOR TH
     1E,/,5X,55HPOWER SPECTRAL DENSITY  PSD  OPTION YOU HAVE PREVIOUSLY,
     2/,5X,52HCHOSEN. TWO PSD NORMALIZATION METHODS ARE AVAILABLE:,//,10
     3X,54HMETHOD 1 -- PSD IS NORMALIZED BY THE I-NORM°TH PROCESS,/,21X,
     429HNOISE MINUS "Q" INORM,INORM .,/,21X,49H NOTE: "Q" IS AN OPTIMAL
     5 STATE WEIGHTING MATRIX. ,/,21X,34HIN THIS METHOD, INORM =0,1,....,
     6NG.,//,10X,63HMETHOD 2 -- PSD IS NORMALIZED BY THE  INORM -NG °TH
     7MEASUREMENT,/,21X,39HNOISE MINUS "R" INORM - NG,INORM - NG .,/,21X
```

```
     8,51H NOTE: "R" IS AN OPTIMAL CONTROL WEIGHTING MATRIX. ,/,21X,44HI
     9N THIS METHOD, INCRM = NG + 1,...,NG + NOB.,//,10X,51HSELECT AN IN
     $TEGER FROM 0 - 16 REPRESENTING YOUR PSD,/,15X,27HNORMALIZATION REQ
     $UIREMENTS.,//,10X,53HIF PSD NORMALIZATION IS NOT DESIRED ENTER "0"
     $  ZERO .)
830   FORMAT (5X,43HANALYSIS COMPLETE. DO YOU WANT ANOTHER RUN?,/,15X,19
     1HTYPE "YES" OR "NO".)
840   FORMAT (///,5X,48HDO YOU WISH TO SAVE THE "F"-MATRIX FROM THE LAST
     1,/,5X,36HRUN TO BE USED IN THE FOLLOWING RUN?,//,5X,39HNOTE: THE M
     2ATRIX WILL BE REDISPLAYED AT,/,5X,34HTHE PROPER INPUT SEQUENCE INT
     3ERVAL,/,5X,40HAND YOU WILL HAVE THE OPTION OF CHANGING,/,5X,27HIND
     4IVIDUAL MATRIX ELEMENTS.,//,15X,19HTYPE "YES" OR "NO".)
850   FORMAT (///,5X,48HDO YOU WISH TO SAVE THE "H"-MATRIX FROM THE LAST
     1,/,5X,36HRUN TO BE USED IN THE FOLLOWING RUN?,//,5X,39HNOTE: THE M
     2ATRIX WILL BE REDISPLAYED AT,/,5X,34HTHE PROPER INPUT SEQUENCE INT
     3ERVAL,/,5X,40HAND YOU WILL HAVE THE OPTION OF CHANGING,/,5X,27HIND
     4IVIDUAL MATRIX ELEMENTS.,//,15X,19HTYPE "YES" OR "NO".)
860   FORMAT (///,5X,48HDO YOU WISH TO SAVE THE "G"-MATRIX FROM THE LAST
     1,/,5X,36HRUN TO BE USED IN THE FOLLOWING RUN?,//,5X,39HNOTE: THE M
     2ATRIX WILL BE REDISPLAYED AT,/,5X,34HTHE PROPER INPUT SEQUENCE INT
     3ERVAL,/,5X,40HAND YOU WILL HAVE THE OPTION OF CHANGING,/,5X,27HIND
     4IVIDUAL MATRIX ELEMENTS.,//,15X,19HTYPE "YES" OR "NO".)
870   FORMAT (///,5X,52HDO YOU WISH TO SAVE THE "GAMMA"-MATRIX FROM THE
     1LAST,/,5X,36HRUN TO BE USED IN THE FOLLOWING RUN?,//,5X,39HNOTE: T
     2HE MATRIX WILL BE REDISPLAYED AT,/,5X,34HTHE PROPER INPUT SEQUENCE
     3 INTERVAL,/,5X,40HAND YOU WILL HAVE THE OPTION OF CHANGING,/,5X,27
     4HINDIVIDUAL MATRIX ELEMENTS.,//,15X,19HTYPE "YES" OR "NO".)
880   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
890   FORMAT (5X,59HOPTSYSX IS A COMPLETELY INTERACTIVE OPTIMAL SYSTEMS
     1CONTROL,/,8X,55HPROGRAM. IT WILL SOLVE NUMEROUS CONTROL PROBLEMS O
     2N THE,/,8X,45HFOLLOWING TYPES OF SYSTEMS CONTROL EQUATIONS:,//,15X
     3,35HXDOT =  F *X +  G *U +  GAM *(W+W0),//,20X,22HMEASUREMENT EQUA
     4TION--,//,15X,21HZ =  H *X +  D *W + V,//,20X,29HREGULATOR PERFORM
     5ANCE INDEX--,//,15X,42HJ = 1/2 * INTEGRAL (Y * A *Y + U * B *U)DT,
     6//,20X,32HSTATE FEEDBACK GAIN DEFINITION--,//,25X,10HU = - C *X,//
     7,15X,45HDO YOU WISH TO CONTINUE?  TYPE "YES" OR "NO".)
900   FORMAT (25X,14H--DATA ENTRY--,//,5X,49HALTHOUGH OPTSYSX IS SPECIFI
     1CALLY DESIGNED TO READ,/,5X,48HALL MATRIX DATA INTERACTIVELY, SEVE
     2RAL ALTERNATE,/,5X,31HMETHODS ARE AVAILABLE TO USERS:,//,10X,43HME
     3THOD 1--THE "F","G", AND "GAMMA" MATRICES,/,13X,37HMAY BE READ FRO
     4M SEPARATE DATA FILES.,//,10X,50HMETHOD 2--THE "F","G", AND "GAMMA
     5" MATRICES MAY BE,/,13X,45HEXPLICITLY DEFINED WITHIN SUBROUTINE "S
     6ETUP".,//,10X,52H NOTE: IN EITHER CASE, THE USER SHOULD OBTAIN A C
     7OPY,/,17X,34HOF THE PROGRAM LISTING AND EXAMINE,/,17X,39HTHE EXAMP
     8LES CONTAINED IN S/R "SETUP". ,//,10X,45HDO YOU WISH TO CONTINUE?
     9 TYPE "YES" OR "NO".)
910   FORMAT (//,5X,46HDO YOU WISH TO INPUT THE "F", "G", AND "GAMMA",/,
     110X,40HMATRICES FROM SUBROUTINE "SETUP" IAW THE,/,10X,40HMETHOD DE
     2SCRIBED ON THE PREVIOUS SCREEN?,//,15X,19HTYPE "YES" OR "NO".)
920   FORMAT (//,41H........OPTSYSX IS NOW TERMINATED........,//)
      END
```

```
C======================================================================
      SUBROUTINE SETUP (BA,G,GAM,NS,NC,NG)
C======================================================================
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION BA(NS,NS),G(NS,NC),GAM(NS,NG),DUM(82,85)
      COMMON /PROG/ IOL,IO,IR,ISS,IP,ITP1,ITP2,ITP3,IPDFW,IE,IDSTAB,IDEB
     1UG,ISET,IREG,IPSD,IYU,INORM
C----------------------------------------------------------------------
C  FILE DEFINITIONS
C----------------------------------------------------------------------
      CALL FBTCMS ('FILEDEF ','03      ','DISK    ','X29A82  ',
     1             'DATA    ','A       ')
C----------------------------------------------------------------------
C  THIS IS AN EXAMPLE OF AN 82 X 85 DATA FILE X29A82 DATA A1 READ FROM
C  A USER'S DISK AND CONVERTED (FROM A "DUMMY" ARRAY NAMED 'DUM') TO A
C  SYMMETRIC ARRAY.  THE FORMAT STATEMENT MUST MATCH YOUR DISK DATA
C  FORMAT OR THE PROGRAM WILL FAIL!  NOTE: ALL PROGRAM DIMENSIONS
C  MUST BE ENLARGED ACCORDINGLY FOR A SYSTEM OF THIS SIZE.
C----------------------------------------------------------------------
      READ (3,50)  ((DUM(I,J),J=1,85),I=1,NS)
      DO 20 I=1,NS
      DO 10 J=1,NS
      BA(I,J)=DUM(I,J)
10    CONTINUE
20    CONTINUE
C----------------------------------------------------------------------
C  THESE ARE EXAMPLES OF SEVERAL POSSIBLE METHODS OF ARRAY GENERATION
C  WITHIN SUBROUTINE SETUP.THE "GAM" ARRAY WAS SET TO ZERO SINCE NO
C  "NOISE" WAS PRESENT, AND THE NON-ZERO ELEMENTS OF THE "G" ARRAY WERE
C  EXPLICITLY DEFINED. THEY COULD ALSO BE READ FROM FILES AS ABOVE.
C----------------------------------------------------------------------
      DO 40 I=1,NS
      DO 30 J=1,NC
      GAM(I,J)=0.0D+00
      G(I,J)=0.0D+00
      G(82,1)=0.1000D+01
30    CONTINUE
40    CONTINUE
      RETURN
C----------------------------------------------------------------------
50    FORMAT (5(E12.4))
      END
```

```
C=======================================================================
      SUBROUTINE CHECK (EPS,NO,NG,NC,IRET)
C     CHECKS THE CONSISTENCY OF REQUESTED OPTIONS.                      =
C=======================================================================
      DOUBLE PRECISION EPS
      COMMON /PROG/ IOL,IQ,IR,ISS,IM,ITF1,ITF2,ITF3,IFDFW,IE,IDSTAB,IDEB
     1UG,ISET,IREG,IPSD,IYU,INORM
C-------SET MODAL ANALYSIS WHEN OL EIGENSYS OR OL TF REQUESTED----------
      IF (IM .EQ. 1 .AND. IOL .EQ. 0) IOL=1
      IF (IOL .EQ. 3 .OR. ITF1 .NE. 0) IM=1
C-----------------CHECK TO SEE IF H MATRIX INPUT------------------------
      IF (NO .NE. 0 .OR. IOL .GE. 2) GO TO 10
      WRITE (5,90)
      IRET=1
      RETURN
10    CONTINUE
C------------------TRANSFER FUNCTION CHECKS-----------------------------
      IF (IE .EQ. 0) IE=6
      EPS=10.**(-IE)
C-----------------------OPEN LOOP TF------------------------------------
      IF (ITF1 .EQ. 0 .OR. NC .NE . 0) GO TO 20
      WRITE (5,100)
      IRET=1
      RETURN
C-----------------------COMPENSATOR TF----------------------------------
20    IF (ITF3 .EQ. 0) GO TO 30
      IF (IREG .EQ. 0 .AND. (NC .NE. 0 .AND. NG .NE. 0)) GO TO 30
      WRITE (5,110)
      IRET=1
      RETURN
30    CONTINUE
C-----------------------NOISE TF----------------------------------------
      IF (ITF2 .EQ. 0) GO TO 40
      IF (NG.NE. 0 .AND. NC .NE. 0) GO TO 40
      WRITE (5,120)
      IRET=1
      RETURN
C------------------DESTABILIZATION RESTRICTIONS-------------------------
40    IF (IDSTAB .EQ. 0) GO TO 50
      IF (NC .EQ. 0) GO TO 50
      IF (NG .NE. 0) IREG=1
      WRITE (5,130)
      IF (IREG .EQ. 1) GO TO 50
      IRET=1
      RETURN
50    CONTINUE
C------------------PSD INPUT--------------------------------------------
      IF (IPSD .EQ. 0) GO TO 80
      IF (IPSD .LT. 0 .OR. IPSD .GT. 3) GO TO 60
      IF (IYU .LT. 0 .OR. IYU .GT. 3) GO TO 60
      IF (INORM .LT. 0 .OR. INORM .GT. NG+NO) GO TO 60
      GO TO 70
60    WRITE (5,140)
      IRET=1
      RETURN
70    IF (IREG .EQ. 0 .AND. NC .NE. 0) GO TO 80
      WRITE (5,150)
      IRET=1
      RETURN
80    CONTINUE
      RETURN
C-----------------------------------------------------------------------
90    FORMAT (//,5X,49H H - MATRIX MUST BE INPUT, I.E. "NO" MUST BE > 0.
     1,//)
100   FORMAT (//,5X,46H(G) MATRIX MUST BE INPUT, I.E. NC MUST BE > 0.,/,
     110X,26HTO COMPUTE OPEN LOOP T. F.,//)
110   FORMAT (//,5X,48HREGULATOR AND FILTER SYNTHESIS MUST BE REQUESTED,
     1/,5X,44HIN THE SAME RUN TO COMPUTE COMPENSATOR T. F.,/,5X,47HI.E.
     2IREG MUST = 0.; "NC" AND "NG" MUST BE > 0.,//)
120   FORMAT (//,5X,51HNOISE T. F. CALCULATED ONLY WHEN REGULATOR DESIGN
     1ED,/,5X,47HI.E. IREG MUST = 1.; "NC" AND "NG" MUST BE > 0.,//)
130   FORMAT (//,5X,47HDESTABILIZATION OPTION DESIGNED FOR A REGULATOR,/
     1,5X,38HOR FILTER BUT NOT BOTH SIMULTANEOUSLY.,//,5X,55HIF "NG" > 0
     2. THE REGULATOR OPTION IS AUTOMATICALLY SET!,//)
140   FORMAT (//,5X,49H ********** INCONSISTENT PSD INPUT FLAGS ********
     1,//)
```

```
150   FORMAT (//,5X,44HBOTH A REGULATOR AND FILTER MUST BE RESIDENT,/,10
     1X,42HTO COMPUTE THE PSD OF A CONTROLLED SYSTEM!,/,10X,42HI.E. IREG
     2 MUST BE 0. AND "NC" MUST BE > 0.,//)
      END
```

```
C=======================================================================
      SUBROUTINE INNER (NS,NC,NO,NG,N2,ACL,B,BA,CI,CR,CQ,CWI,CWR,D,FBGC,
     1FBGE,G,GAM,GM,GN,HO,D1,D2,PRO,RM,RC,Q,SC,WR,WI,W11,W21,X,WNORM,WNO
     2RMI,DESTAB,AA,BM,CM,JCP,RES,AY,BB,CC,CP,GW,GV,HY,HU,DSTORE,ISAF,IS
     3AH,ISAG,IGAM,IBET,PRTT,NRCW,NCCL)
C=======================================================================
      IMPLICIT REAL*8(A-H,O-Z)
C-----------------------------------------------------------------------
      DIMENSION ACL(NS,NS),B(NC,NC),BA(NS,NS),CI(NS),CR(NS),CQ(NS,NS),CW
     1I(NS),CWR(NS),FBGC(NC,NS),FBGE(NS,NO),G(NS,NS),GM(NS,NS),PRO(NS,NS
     2),RC(NO,NC),SC(NS,NS),WR(N2),WI(N2),W11(NS,NS),W21(NS,NS),X(N2,N2)
     3,GN(NS,NS),HO(NC,NS),D1(N2),D2(N2),RM(N2,N2),Q(NG,NG),D(NO,NC),GAM
     4(NS,NG),WNORM(NS,NS),WNORMI(NS,NS),DESTAB(NS),AA(NS,NS),BM(NS,NC),
     5CM(NO,NS),JCP(N2),RES(N2),AY(NC,NC),BB(N2),CC(N2),CP(NS),GW(N2,NG)
     6,GV(N2,NC),HY(NO,N2),HU(NC,N2),DSTORE(NS,NS),PRTT(16,16)
C-----------------------------------------------------------------------
      COMMON /PROG/ IOL,IQ,IR,ISS,IM,ITF1,ITF2,ITF3,IFDFW,IE,IDSTAB,IDEB
     1UG,ISET,IBEG,IFSD,IYU,INORM
C-----------------------------------------------------------------------
      REAL*4 FMT(20)
C-----------------------OUTPUT OPTIONS----------------------------------
C---IOL=1 IF THE OPEN LOOP EIGENSYSTEM IS DESIRED--OTHERWISE IOL=0
C---IQ=1 IF THE RMS VALUES OF THE CONTROL AND STATE ARE TO BE FOUND
C---IR=0 IF OPTIMAL FILTER AND REGULATOR EIGENSYSTEMS ARE TO BE FOUND
C---IR=1 IF EXTERNAL C MATRIX IS SUPPLIED
C---IR=2 IF EXTERNAL K IS SUPPLIED
C---IR=3 IF EXTERNAL C AND K ARE SUPPLIED
C---ISS=1 IF STEADY STATE VALUES ARE TO BE DETERMINED
C---IM=1 IF MODAL STATES DESIRED
C-----------------------------------------------------------------------
      NSQ=NS*NS
      MH=NS
      M=N2
      CALL CHECK (EPS,NC,NG,NO,IRET)
      IF (IRET.EQ.1) RETURN
      IF (ISET.EQ.1) GO TO 20
      CALL READF (NS,ISAF,BA)
      IF (IDSTAB.EQ.0) GO TO 10
      WRITE (5,1800)
      CALL RDREAL (ANSR)
      DSTAB=ANSR
      DO 10 I=1,NS
      DESTAB(I)=DSTAB
10    CONTINUE
      GO TO 30
20    CALL SETUP (BA,G,GAM,NS,NG,NC)
30    CONTINUE
      WRITE (6,1380)
      DO 40 I=1,NS
40    WRITE (6,1390) (BA(I,J),J=1,NS)
      IF (IDSTAB.EQ.0) GO TO 50
      WRITE (6,1480)
      WRITE (6,1390) (DESTAB(I),I=1,NS)
50    CONTINUE
C---------------EIGENSYSTEM OF THE OPEN LOOP DYNAMICS-------------------
      IF (IOL.EQ.0.AND.IQ.EQ.0) GO TO 90
      IF (IOL.EQ.0.AND.NC.NE.0) GO TO 90
      DO 60 I=1,NS
      DO 60 J=1,NS
60    GN(I,J)=BA(I,J)
      CALL BALANC (NS,NS,GN,LOW,IHIGH,D1)
      CALL ORTHES (NS,NS,LOW,IHIGH,GN,D2)
      CALL ORTRAN (NS,NS,LOW,IHIGH,GN,D2,SC)
      CALL HQR2 (NS,NS,LOW,IHIGH,GN,CWR,CWI,SC,IERR)
      IF (IERR.NE.0) CALL EREXIT (NS,GN,IERR)
      CALL BALBAK (NS,NS,LOW,IHIGH,D1,NS,SC)
C-----------NORMALIZE AND PRINT OPEN LOOP EIGENSYSTEM-------------------
      IWRITE=1
      CALL CNORM (CWR,CWI,SC,NS,IWRITE,NSQ,DDD,D1,D2,WNORM,WNORMI,HC,CM,
     1NO,NS)
      IF (IOL.EQ.2) RETURN
      IF (IQ.EQ.0.OR.(NC.NE.0.OR.IDSTAB.GT.0)) GO TO 90
      DO 70 I=1,NS
      IF (CWR(I).LT.0.) GO TO 70
      WRITE (5,1490)
      RETURN
```

```
70     CONTINUE
       IF (IOL.EQ.3)  GO TO  130
       DO 80  I=1,NS
       DO 80  J=1,NS
80     W11(I,J)=SC(I,J)
       CALL MINV (NSQ,W11,NS,DDD,D1,D2)
90     CONTINUE
       IF (IDSTAB.EQ.0)  GO TO 130
C----------------- FORM U * DIAG(DESTAB)  * U-INV----------------------
       DO 100 J=1,NS
       DO 100 I=1,NS
100    AA(I,J)=WNORM(I,J)*DESTAB(J)
       DO 120 I=1,NS
       DO 120 J=1,NS
       DDD=0.D0
       DO 110 K=1,NS
110    DDD=DDD+AA(I,K)*WNORMI(K,J)
       DSTORE(I,J)=DDD
120    BA(I,J)=BA(I,J)+DDD
130    CONTINUE
       CALL READH (NC,NS,ISAH,HO)
       WRITE (6,1440)
       DO 140 I=1,NO
140    WRITE (6,1390)  (HO(I,J),J=1,NS)
       IF (IM.NE.1)  GO TO 150
       CALL MODE (WNORM,HO,CM,NS,NC,NS,2)
150    CONTINUE
       IF (IFDFW.EQ.0) GO TO 170
       CALL READD (NC,NC,D)
       WRITE (6,1470)
       DO 160 I=1,NO
160    WRITE (6,1390)  (D(I,J),J=1,NC)
170    CONTINUE
       NOB=0
       IF (NC.EQ.0)  GO TO 590
       IF (IOL.EQ.3)  GO TO 270
       IF (IR.NE.1.AND.IR.NE.3)  GO TO 210
       IF (ISET.EQ.1) GO TO 180
       CALL READG (NS,NC,ISAG,G)
180    CONTINUE
       CALL READFB (NC,NS,FBGC)
       WRITE (6,1400)
       DO 190 I=1,NS
190    WRITE (6,1390)  (G(I,J),J=1,NC)
       IF (IM.NE.1)  GO TO 200
       CALL MODE (WNORMI,G,BM,NS,NS,NC,0)
200    CONTINUE
       GO TO 330
210    DO 220 I=1,NS
       DO 220 J=1,NS
220    RM(I+MH,J)=0.0
       CALL READAY (NO,AY)
       DO 240 I=1,NO
       DO 240 J=1,NS
       DDD=0.D0
       DO 230 K=1,NO
230    DDD=DDD+AY(I,K)*EC(K,J)
240    AA(I,J)=DDD
       WRITE (6,1460)
       DO 250 I=1,NO
250    WRITE (6,1390)  (AY(I,J),J=1,NC)
       DO 260 I=1,NS
       DO 260 J=1,NS
       DO 260 K=1,NO
260    RM(I+MH,J)=RM(I+MH,J)+AA(K,I)*HO(K,J)
270    IF (ISET.EQ.1)  GO TO 280
       CALL READG (NS,NC,ISAG,G)
280    CONTINUE
       IF (IOL.EQ.3)  GO TO 290
       CALL READE (NC,E)
290    WRITE (6,1400)
       DO 300 I=1,NS
300    WRITE (6,1390)  (G(I,J),J=1,NC)
       IF (IM.NE.1)  GO TO 310
       CALL MODE (WNORMI,G,BM,NS,NS,NC,0)
310    CONTINUE
```

```
      IF (IOL.EQ.3)  GO TO 340
      WRITE (6,1410)
      DO 320 I=1,NC
320   WRITE (6,1390)  (B(I,J),J=1,NC)
330   IF (ITF1.EQ.0)  GO TO 350
C-------------------OPEN LOOP TRANSFER FUNCTIONS------------------------
340   WRITE (6,1500)
      ITFX=1
      CALL TF (NS,NS,NSQ,BA,AA,NC,G,BM,NO,HO,CM,IPDFW,D,BB,CC,CP,WR,WI,C
     1WR,CWI,SC,JCF,RES,D1,D2,DDD,EPS,ITF1,ITFX)
350   IF (IOL.NE.3)  GO TO 360
      IF (NG.EQ.0)  RETURN
      GO TO 600
360   CONTINUE
      IF (IR.EQ.1.OR.IR.EQ.3)  GO TO 500
C---CALCULATION OF CONTROL GAINS:FORMATION OF CONTROL HAMILTONIAN-------
C
C                                                ***F AND FT ARE THE OPEN LOOP
C    ┌--                             --┐              DYNAMICS MATRIX AND TRANSPOSE
C    |        F           -GM*BI*GMT   |         ***BI IS NCXNC CONTROL WEIGHTING
C    |                                 |            MATRIX
C    |                                 |         ***A IS THE NSXNS STATE WEIGHTING
C    |                                 |            MATRIX
C    |       -A                -FT     |
C    ---                             ---         ***GM IS THE NSXNC CONTROL
C                                                   DISTRIBUTION MATRIX
C-----------------------------------------------------------------------
      DO 370 I=1,NC
      DO 370 J=1,MH
370   PRO(I,J)=G(J,I)/B(I,I)
      DO 380 I=1,MH
      DO 380 J=1,MH
      RM(I,J+MH)=0.D0
      DO 380 K=1,NC
380   RM(I,J+MH)=RM(I,J+MH)-G(I,K)*PRO(K,J)
C-------------------2NX2N HAMILTONIAN MATRIX----------------------------
C----------------DIAGONAL BLOCKS---M11 AND M22--------------------------
      DO 390 I=1,MH
      DO 390 J=1,MH
      RM(I,J)=BA(I,J)
      RM(I+MH,J+MH)=-BA(J,I)
C---------------------------M21 BLOCK-----------------------------------
390   RM(I+MH,J)=-RM(I+MH,J)
C--------------M12 BLOCK IS DEFINED IN LINE 430 ABOVE------------------
400   CONTINUE
      IF (IDEBUG.EQ.0)  GO TO 410
      WRITE (6,1510)
      CALL RAPRNT (M,M,M,9,RM,4,'(9(1X,1PD13.6))')
410   CALL BALANC (M,M,RM,LOW,IHIGH,D1)
      CALL ORTHES (M,M,LOW,IHIGH,RM,D2)
      CALL ORTRAN (M,M,LOW,IHIGH,RM,D2,X)
      CALL HQR2 (M,M,LOW,IHIGH,RM,WR,WI,X,IERR)
      IF (IERR .NE.  0)  CALL EREXIT  (M,RM,IERR)
      CALL BALBAK (M,M,LOW,IHIGH,D1,M,X)
C------------DEBUG DIAGNOSTICS ON EULER-LAGRANGE EQUATIONS--------------
      IF (IDEBUG .EQ.  0)  GO TO  430
      WRITE  (6,1520)
      DO 420  I=1,M
420   WRITE  (6,1530)  WR(I),WI(I)
      WRITE  (6,1540)
      CALL RAPRNT  (M,M,M,9,X,4,'(9(1X,1PD13.6))')
430   CONTINUE
      IF  (IDSTAB .EQ.  1)  GO TO 440
      IF  (NOB.EQ.0)  WRITE  (6,1550)
      IF  (NOB.NE.0)  WRITE  (6,1560)
440   IF  (NOB.NE.  0)  GO TO 750
      CALL RGAIN (M,NS,NC,NOB,WR,WI,X,GN,W11,RM,W21,D1,CWR,CWI,SC,MHS,D2
     1)
C---------------------------CHECK EIGENVECTORS---------------------------
      IF (IDEBUG .EQ.  0)  GO TO  450
      WRITE  (6,1570)
      CALL RAPRNT  (NS,NS,NS,9,SC,4,'(9(1X, 1PD13.6))')
450   CONTINUE
C------RESET FLAG AND F MATRIX FOR ITERATIVE DESTABILIZATION CASE-------
      IF (IDSTAB .EQ.  0)  GO TO  470
      DO 460  I=1,NS
```

```
460    BA(I,I)=BA(I,I)-DESTAB(I)
       IR=1
470    CONTINUE
C-------------------CALCULATION OF FEEDBACK GAIN-------------------------
C-------------FEEDBACK GAINS--->  U = -(BINVERSE)*GT*GN -----------------
C--------------------------CALCULATE GT----------------------------------
       DO 490 I=1,NC
       DO 490 J=1,NS
       PRO(I,J)=0.D0
       DO 480 K=1,MH
480    PRO(I,J)=PRO(I,J)+G(K,I)*GN(K,J)
490    FBGC(I,J)=-PRO(I,J)/B(I,I)
       IF (IDSTAB .EQ. 1) GO TO 500
C---------NORMALIZE AND PRINT OPT. REG. CLOSED LOOP EIGENSYSTEM----------
       IWRITE=2
       CALL CNORM (CWR,CWI,SC,NS,IWRITE,NSQ,DDD,D1,D2,WNORM,WNORMI,FBGC,
      1AA,NC,NS)
C-----------------THE OPTIMUM FEEDBACK CONTROL GAINS---------------------
500    WRITE (6,1580)
       DO 510 I=1,NC
510    WRITE (6,1590) (FBGC(I,J),J=1,NS)
C------COMPUTE MODAL C MATRIX  OPEN LOOP U-INVERSE SAVED IN WNORMI -----
       IF (IM .NE. 1) GO TO 530
C-----------------------------------------------------------------------
C IN COMPUTING MODAL C RECOMPUTE U OPEN LOOP SINCE WNORM USED TO STORE
C U & U-INV FOR CLOSED LOOP SYSTEMS; WNORMI USED TO SAVE U-INV OPEN LOOP
C-----------------------------------------------------------------------
       DO 520 I=1,NS
       DO 520 J=1,NS
520    WNORM(I,J)=WNORMI(I,J)
       CALL MINV (NSQ,WNORM,NS,DDD,D1,D2)
       CALL MODE (WNORM,FBGC,AA,NS,NC,NS,3)
530    CONTINUE
C------------------THE CLOSED LOOP DYNAMICS MATRIX----------------------
       DO 550 I=1,NS
       DO 550 J=1,NS
       SUM=0.D0
       DO 540 K=1,NC
540    SUM=SUM+G(I,K)*FBGC(K,J)
550    ACL(I,J)=BA(I,J)+SUM
       WRITE (6,1600)
       CALL RAPRNT (MH,MH,MH,5,ACL,4,'(5(1X,1PD13.6))')
       IF (IR.NE.1.AND.IR.NE.3) GO TO 590
       DO 560 I=1,NS
       DO 560 J=1,NS
560    GN(I,J)=ACL(I,J)
       CALL BALANC (NS,NS,GN,LOW,IHIGH,D1)
       CALL ORTHES (NS,NS,LOW,IHIGH,GN,D2)
       CALL ORTRAN (NS,NS,LOW,IHIGH,GN,D2,SC)
       CALL HQR2 (NS,NS,LOW,IHIGH,GN,CWR,CWI,SC,IERR)
       IF (IERR .NE. 0) CALL EREXIT (NS,GN,IERR)
       CALL BALBAK (NS,NS,LOW,IHIGH,D1,NS,SC)
C-------NORMALIZE AND PRINT CLOSED LOOP SUBOPT. REG. EIGENSYSTEM--------
       IWRITE=3
       CALL CNORM (CWR,CWI,SC,NS,IWRITE,NSQ,DDD,D1,D2,WNORM,WNORMI,FBGC,
      1AA,NC,NS)
       DO 570 I=1,NS
       IF (CWR(I).LT.0.0) GO TO 570
       WRITE (5,1610)
       RETURN
570    CONTINUE
       IF (IQ.NE.1) GO TO 590
       DO 580 I=1,NS
       DO 580 J=1,NS
580    W11(I,J)=SC(I,J)
       CALL MINV (NSQ,W11,NS,DDD,D1,D2)
590    NOB=NO
       IF ( NG .EQ. 0) RETURN
600    IF (ISET.EQ.1) GO TO 610
       CALL READG2 (NS,NG,IGAM,GAM)
610    CONTINUE
       IF (IOL .EQ. 3) GO TO 620
       CALL READQ (NG,Q)
620    WRITE (6,1420)
       DO 630 I=1,NS
630    WRITE (6,1390) (GAM(I,J),J=1,NG)
```

```
      IF (IM.NE.1) GO TO 640
      CALL MODE (WNORMI,GAM,AA,NS,NS,NG,1)
640   CONTINUE
      IF (IOL .EQ. 3) RETURN
      WRITE (6,1430)
      DO 650 I=1,NG
650   WRITE (6,1390) (Q(I,J),J=1,NG)
      IF ((IQ.EQ.0).AND.(NG.EQ.0)) GO TO 1260
      DO 660 I=1,NG
      DO 660 J=1,NS
      PRO(I,J)=0.D0
      DO 660 K=1,NG
660   PRO(I,J)=PRO(I,J)+Q(I,K)*GAM(J,K)
      DO 670 I=1,NS
      DO 670 J=1,NS
      CQ(I,J)=0.D0
      DO 670 K=1,NG
670   CQ(I,J)=CQ(I,J)-GAM(I,K)*PRO(K,J)
      IF (IREG .EQ. 1) GO TO 690
C---CALCULATION OF FILTER GAINS:FORMATION OF ESTIMATION HAMILTONIAN-----
C                                                                      =
C                                            ***F AND FT ARE SAME AS FOR  =
C    T--                     --T                CONTROL HAMILTONIAN       =
C    |      F         -GM*Q*GMT |            ***Q IS NGXNG STATE DISTURBANCE =
C    |                          |               RCOVARIANCE               =
C    |                          |            ***R IS NOXNO MEASUREMENT NOISE  =
C    |                          |               RCOVARIANCE               =
C    | -HOT*RIN*HO       -FT    |            ***HC IS NOXNS MEASUREMENT MATRIX=
C    ---                      ---            ***GM IS NSXNG STATE DISTURBANCE =
C                                               DISTRIBUTION MATRIX       =
C----------------------------------------------------------------------
      CALL READR (NO,RC)
      WRITE (6,1450)
      DO 680 I=1,NO
680   WRITE (6,1390) (RC(I,J),J=1,NC)
690   IF (ITF2 .EQ. 0) GO TO 700
C--------------------NOISE TRANSFER FUNCTIONS---------------------------
      WRITE (6,1620)
      ITFX=2
      IZERO=0
      CALL TF (NS,NS,NSQ,ACL,AA,NG,GAM,BM,NO,HC,CM,IZERO,D,BB,CC,CP,WR,
     1WI,CWR,CWI,SC,JCP,RES,D1,D2,DDL,EPS,ITF2,ITFX)
      IF (IREG .EQ. 1) RETURN
700   CONTINUE
      IF (IREG .EQ. 1) GO TO 930
      IF (IR.LT.2) GO TO 710
      CALL READFE (NS,NC,FEGE)
      GO TO 810
710   CONTINUE
C-----------THE MEASUREMENT MATRIX (HOT*RIN*HO===>SC--------------------
      DO 720 I=1,NO
      DO 720 J=1,MH
720   PRO(I,J)=HO(I,J)/RC(I,I)
      DO 730 I=1,MH
      DO 730 J=1,MH
      RM(I+MH,J)=0.D0
      DO 730 K=1,NO
730   RM(I+MH,J)=RM(I+MH,J)-HO(K,I)*PRO(K,J)
C------------------------------GM*Q*GMT===>CC--------------------------
      DO 740 I=1,NS
      DO 740 J=1,NS
      RM(I,J)=EA(I,J)
      RM(I+MH,J+MH)=-EA(J,I)
740   RM(I,J+NS)=CQ(I,J)
      GO TO 400
C-GO BACK TO 450 TO SET UP THE FILTER HAMILTONIAN; CALC.THE FILTER GAINS
750   CALL RGAIN (M,NS,NC,NOB,WR,WI,X,GN,GM ,RM,W21,D1,CR,CI,PRO,MHS,D2)
C--------------------------CHECK EIGENVECTORS---------------------------
      IF (IDEBUG .EQ. 0) GO TO 760
      WRITE (6,1570)
      CALL RAPENT (NS,NS,NS,9,PRO,4,'(9(1X,1PD13.6))')
760   CONTINUE
      IF (IDSTAB .EQ. 1) GO TO 770
C------------NORMALIZE AND PRINT OPT. ESTIMATOR EIGENSYSTEM-------------
      IWRITE=4
      CALL CNORM (CR,CI,PRO,NS,IWRITE,NSQ,DDD,D1,D2,WNORM,WNORMI,HO,AA,
```

```
     1NO,NS)
770   DO 780 I=1,MH
      DO 780 J=1,NO
780   PBC(I,J)=+HO(J,I)/RC(J,J)
      DO 790 I=1,MH
      DO 790 J=1,NO
      PBGE(I,J)=0.D0
      DO 790 K=1,MH
790   PBGE(I,J)=PBGE(I,J)+GN(I,K)*PBC(K,J)
      IF (IDSTAB .EQ. 1) GO TO 810
      WRITE (6,1670)
      CALL RAPRNT (MH,MH,MH,5,GN,4,'(5(1X,1PD13.6))')
      WRITE (6,1680)
      DO 800 I=1,MH
800   X(I,I)=DSQRT(GN(I,I))
      WRITE (6,1690) (X(I,I),I=1,MH)
810   WRITE (6,1630)
      DO 820 I=1,MH
820   WRITE (6,1640) (PBGE(I,J),J=1,NO)
C---------COMPUTE MODAL K MATRIX  OPEN LOOP U-INV SAVED IN WNORMI -------
      IF (IM .NE. 1) GO TO 830
      CALL MODE (WNORMI,PBGE,AA,MH,MH,NO,4)
830   CONTINUE
C------RESET FLAG AND F MATRIX FOR ITERATIVE DESTABILIZATION CASE-------
      IF (IDSTAB .EQ. 0) GO TO 850
      DO 840 I=1,NS
      DO 840 J=1,NS
840   BA(I,J)=BA(I,J)-DSTORE(I,J)
      IR=2
850   CONTINUE
      DO 870 I=1,NS
      DO 870 J=1,NS
      SUM=0.0
      DO 860 K=1,NO
860   SUM=SUM+PBGE(I,K)*HC(K,J)
870   PRO(I,J)=BA(I,J)-SUM
      WRITE (6,1650)
      CALL RAPRNT (NS,NS,NS,5,PRO,4,'(5(1X,1PD13.6))')
      IF (IR .LT. 2) GO TO 890
      CALL BALANC (NS,NS,PRO,LOW,IHIGH,D1)
      CALL ORTHES (NS,NS,LOW,IHIGH,PRO,D2)
      CALL ORTRAN (NS,NS,LOW,IHIGH,PRO,D2,GM)
      CALL HQR2 (NS,NS,LOW,IHIGH,PRO,CR,CI,GM,IERR)
      IF (IERR .NE. 0) CALL ERREXIT (NS,PRO,IERR)
      CALL BALBAK (NS,NS,LOW,IHIGH,D1,NS,GM)
      WRITE (6,1560)
C-----------NORMALIZE AND PRINT SUBOPT. ESTIMATOR EIGENSYSTEM-----------
      IWRITE=5
      CALL CNORM (CR,CI,GM,NS,IWRITE,NSQ,DDD,D1,D2,WNORM,WNORMI,HO,AA,
     1NC,NS)
      DO 880 I=1,NS
      IF (CR(I).LT.0.0) GO TO 880
      WRITE (5,1660)
      RETURN
880   CONTINUE
      GO TO 900
890   IF (IQ.EQ.0) GO TO 1260
900   DO 910 I=1,NO
      DO 910 J=1,MH
      PRC(I,J)=0.D0
      DO 910 K=1,NO
910   PRC(I,J)=PRO(I,J)+RC(I,K)*PBGE(J,K)
      DO 920 I=1,MH
      DO 920 J=1,MH
      CQ(I,J)=C.D0
      DO 920 K=1,NO
920   CQ(I,J)=CQ(I,J)-PBGE(I,K)*PRO(K,J)
930   CONTINUE
C-------------------THE RMS STATE AND CONTROL RESPONSES-----------------
      IR=IR+1
      GO TO (1090,1090,940,940), IR
940   DO 950 I=1,NS
      DO 950 J=1,NG
      X(I,J)=0.0
      DO 950 K=1,NG
950   X(I,J)=X(I,J)+GAM(I,K)*Q(K,J)
```

```
      DO 970  I=1,NS
      DO 970  J=I,NS
      SUM=0.0
      DO 960  K=1,NG
960   SUM=SUM-X(I,K)*GAM(J,K)
      PRO(I,J)=SUM+CQ(I,J)
      PRO(J,I)=PRO(I,J)
      CQ(I,J)=SUM
      CQ(J,I)=SUM
      W21(I,J)=GM(I,J)
970   W21(J,I)=GM(J,I)
      CALL MINV (NSQ,W21,NS,DDD,D1,D2)
      CALL SCOV (NS,GM,W21,CR,CI,NS,GM,W21,CR,CI,PRO,GN)
      WRITE (6,1670)
      CALL RAPRNT (MH,MH,MH,5,GN,4,'(5(1X,1PD13.6))')
      WRITE (6,1680)
      DO 980  I=1,MH
980   X(I,I)=DSQRT(GN(I,I))
      WRITE (6,1690)  (X(I,I),I=1,MH)
      IF (IQ.EQ.0)  GO TO 1260
      DO 1000  I=1,NC
      DO 1000  J=1,NS
      SUM=0.0
      DO 990  K=1,NS
990   SUM=SUM+FBGC(I,K)*GN(K,J)
1000  X(I,J)=SUM
      DO 1020  I=1,NS
      DO 1020  J=1,NS
      SUM=0.0
      IF (NC.EQ.0)  GO TO 1020
      DO 1010  K=1,NC
1010  SUM=SUM+G(I,K)*X(K,J)
1020  PRO(I,J)=CQ(I,J)+SUM
      CALL SCOV (NS,SC,W11,CWR,CWI,NS,GM,W21,CR,CI,PRO,BA)
      IF (NC.EQ.0)  GO TO 1040
      DO 1030  I=1,NC
      DO 1030  J=1,NS
      W21(I,J)=0.0
      DO 1030  K=1,NS
1030  W21(I,J)=W21(I,J)+FBGC(I,K)*BA(J,K)
1040  DO 1060  I=1,NS
      DO 1060  J=1,NS
      SUM=0.0
      IF (NC.EQ.0)  GO TO 1060
      DO 1050  K=1,NC
1050  SUM=SUM+G(I,K)*W21(K,J)
1060  PRO(I,J)=SUM
      DO 1070  I=1,NS
      DO 1070  J=I,NS
      PRO(I,J)=PRO(I,J)+CQ(I,J)+PRO(J,I)
1070  PRO(J,I)=PRO(I,J)
      CALL SCOV (NS,SC,W11,CWR,CWI,NS,SC,W11,CWR,CWI,PRO,CQ)
      DO 1080  I=1,NS
      DO 1080  J=I,NS
      GM(I,J)=CQ(I,J)-BA(I,J)-BA(J,I)+GN(I,J)
1080  GM(J,I)=GM(I,J)
      GO TO 1100
1090  CALL SCOV (NS,SC,W11,CWR,CWI,NS,SC,W11,CWR,CWI,CQ,GM)
1100  IF (NC.EQ.0)  GO TO 1150
      DO 1120  I=1,NS
      DO 1120  J=1,NC
      PRO(I,J)=0.D0
      DO 1110  K=1,NS
1110  PRO(I,J)=PRO(I,J)+GM(I,K)*FBGC(J,K)
1120  CONTINUE
      DO 1140  I=1,NC
      DO 1140  J=1,NC
      SC(I,J)=0.D0
      DO 1130  K=1,NS
1130  SC(I,J)=SC(I,J)+FBGC(I,K)*PRO(K,J)
1140  CONTINUE
1150  IF (IREG .EQ. 0)  GO TO 1170
      DO 1160  I=1,NS
      DO 1160  J=1,NS
1160  CQ(I,J)=GM(I,J)
      GO TO 1190
```

```
1170   WRITE (6,1700)
       CALL RAPRNT (MB,MB,MB,5,GM,4,'(5(1X, 1PD13.6))')
       IF (IR.GT.2) GO TO 1190
       DO 1180 I=1,MB
       DO 1180 J=1,MB
1180   CQ(I,J)=GN(I,J)+GM(I,J)
1190   CONTINUE
       WRITE (6,1710)
       CALL RAPRNT (MB,MB,MB,5,CQ,4,'(5(1X, 1PD13.6))')
       IF (NC.EQ.0) GO TO 1210
       WRITE (6,1720)
       DO 1200 I=1,NC
1200   WRITE (6,1730) (SC(I,J),J=1,NC)
1210   DO 1220 I=1,NS
1220   CQ(I,I)=DSQRT(CQ(I,I))
       IF (NC.EQ.0) GO TO 1240
       DO 1230 I=1,NC
1230   SC(I,I)=DSQRT(SC(I,I))
1240   WRITE (6,1740)
       DO 1250 I=1,NS
       IF (I.LE.NC) WRITE (6,1750) CQ(I,I),SC(I,I)
       IF (I.GT.NC) WRITE (6,1750) CQ(I,I)
1250   CONTINUE
1260   IF (ITF3 .EQ. 0) GO TO 1290
C-------FORM COMPENSATOR FROM MEAS TO INPUT AND COMPUTE TF--------------
       DO 1280 I=1,NS
       DO 1280 J=1,NS
       SUM=0.D0
       DO 1270 K=1,NO
1270   SUM=SUM+FBGE(I,K)*HO(K,J)
1280   CQ(I,J)=ACL(I,J)-SUM
       WRITE (6,1760)
       ITFX=3
       IZERO=0
       CALL TF (NS,NS,NSQ,CQ,AA,NO,FBGE,BM,NC,FBGC,CM,IZERO,D,BB,CC,CP,
      1WR,WI,CWR,CWI,SC,JCF,RES,D1,D2,DDD,EPS,ITF3,ITFX)
1290   CONTINUE
C----------COMPUTE PSD FUNCTIONS OF THE CONTROLLED SYSTEM----------------
       IF (IPSD .EQ. 0) GO TO 1310
       IF (IYU .LT. 3) GO TO 1300
       CALL PSDCAL (M,NS,RM,X,NC,GW,GV,FBGC,NO,HY,HU,HO,FBGE,NG,
      1 GAM,ACL,BA,WR,WI,D1,D2,JCF,RES,Q,RC,BB,CC,1   ,IPSD,INORM)
       CALL PSDCAL (M,NS,RM,X,NC,GW,GV,FBGC,NO,HY,HY,HO,FBGE,NG,
      1 GAM,ACL,BA,WR,WI,D1,D2,JCF,RES,Q,RC,BB,CC,2   ,IPSD,INORM)
       GO TO 1310
1300   CALL PSDCAL (M,NS,RM,X,NC,GW,GV,FBGC,NO,HY,HU,HO,FBGE,NG,
      1 GAM,ACL,BA,WR,WI,D1,D2,JCF,RES,Q,RC,BB,CC,IYU,IPSD,INORM)
1310   IF (ISS .EQ. 0) RETURN
       IF (NC .NE. 0) GO TO 1330
       DO 1320 I=1,NS
       DO 1320 J=1,NS
1320   ACL(I,J)=BA(I,J)
1330   CONTINUE
       CALL MINV (NSQ,ACL,NS,DDD,D1,D2)
       CALL READW (NG,WR)
       WRITE (6,1770) (WR(I),I=1,NG)
       WRITE (6,1780)
       DO 1340 I=1,NS
       WI(I)=0.0
       DO 1340 J=1,NG
1340   WI(I)=WI(I)+GAM(I,J)*WR(J)
       DO 1360 I=1,NS
       CR(I)=0.0
       DO 1350 J=1,NS
1350   CR(I)=CR(I)-ACL(I,J)*WI(J)
1360   WRITE (6,1390) CR(I)
       DO 1370 I=1,NC
       CI(I)=0.0
       DO 1370 J=1,NS
1370   CI(I)=CI(I)+FBGC(I,J)*CR(J)
       WRITE (6,1790) (CI(I),I=1,NC)
       RETURN
C-----------------------------------------------------------------------
C670   FORMAT (2X,1P6D14.6,/,2X,6D14.6)
1380   FORMAT (//,5X,45HOPEN LOOP DYNAMICS MATRIX.................F..,//)
1390   FORMAT (10(2X,0PD11.4))
```

```
1400  FORMAT (//,5X,45HTHE CONTROL DISTRIBUTION MATRIX...........G..,//)
1410  FORMAT (//,5X,45HTHE CONTROL COST MATRIX...................B..,//)
1420  FORMAT (//,5X,45HPROCESS NOISE DISTRIBUTION MATRIX.....GAMMA..,//)
1430  FORMAT (//,5X,45HPOWER SPECTRAL DENSITY - PROCESS NOISE....Q..,//)
1440  FORMAT (//,5X,45HMEASUREMENT SCALING MATRIX................H..,//)
1450  FORMAT (//,5X,45HPOWER SPECTRAL DENSITY-MEASUREMENT NOISE..R..,//)
1460  FORMAT (//,5X,45HOUTPUT COST MATRIX........................A..,//)
1470  FORMAT (//,5X,45HMEASUREMENT FEEDTHROUGH MATRIX............D..,//)
1480  FORMAT (//,25X,28H....DESTABILIZATION CASE....,//,10X,39HTHE FOLLO
     1WING VALUES WILL BE ADDED DOWN,/,10X,49HTHE DIAGONAL OF THE "F" MA
     2TRIX TO DESTABILIZE IT.,/,10X,41HOPTIMAL GAINS FOR THE DESTABILIZE
     3D SYSTEM,/,10X,39HARE THEN USED AS FIXED SUBOPTIMAL GAINS,/,10X,28
     4HFOR THE SYSTEM CALCULATIONS.,//)
1490  FORMAT (///43H PROGRAM TERMINATING DUE TO UNSTABLE SYSTEM)
1500  FORMAT (//,2X,31HOPEN LOOP TRANSFER FUNCTIONS...)
1510  FORMAT (//,5X,32H EULER-LAGRANGE SYSTEM MATRIX...,//)
1520  FORMAT (//,1X,43HEIGENVALUES AND EIGENVECTORS OF THE 2N X 2N,/,2X,
     145HEULER-LAGRANGE SYSTEM AFTER HQR2.............,//)
1530  FORMAT (1X,1P2D13.6)
1540  FORMAT (1X)
1550  FORMAT (//,2X,41HEIGENSYSTEM OF OPTIMAL REGULATOR.........,//)
1560  FORMAT (//,2X,41HEIGENSYSTEM OF OPTIMAL ESTIMATOR.........,//)
1570  FORMAT (//,5X,39H EIGENVECTORS FROM RGAIN PRIOR TO CNORM,//)
1580  FORMAT (//,1X,57HTHE OPTIMAL FEEDBACK GAIN CONTROL MATRIX...C=BINV
     1*GT*S...,//)
1590  FORMAT (10(2X,1PD11.4))
1600  FORMAT (//,2X,45HTHE CLOSED LOOP DYNAMICS MATRIX ......F-G*C..,//)
1610  FORMAT (///,60H   PROGRAM TERMINATING DUE TO UNSTABLE CLOSED LOOP
     1    SYSTEM)
1620  FORMAT (//,2X,61HNOISE TRANSFER FUNCTIONS ,32HTHROUGH THE CLOSED L
     1OOP SYSTEM..,//)
1630  FORMAT (//,5X,45HFILTER STEADY STATE GAINS.................K..,//)
1640  FORMAT (1X,2X,1P6D14.6)
1650  FORMAT (//,1X,43HTHE CLOSED LOOP FILTER DYNAMICS MATRIX IS..,//)
1660  FORMAT (////,43H PROGRAM TERMINATING DUE TO UNSTABLE FILTER)
1670  FORMAT (//,5X,45HTHE COVARIANCE OF THE ESTIMATION ERROR....P..,//)
1680  FORMAT (//,5X,45HRMS VALUES OF THE ESTIMATION ERROR............,//)
1690  FORMAT ((5(1X,1PD13.6)))
1700  FORMAT (//,5X,45HTHE COVARIANCE OF THE ESTIMATE.........XHAT..,//)
1710  FORMAT (//,5X,45HTHE STATE COVARIANCE MATRIX.....X=XHAT + P...,//)
1720  FORMAT (//,5X,45HTHE CONTROL COVARIANCE.........U=C*XHAT*CT...,//)
1730  FORMAT (1P6D14.6)
1740  FORMAT (//,2X,18HSTATE RMS RESPONSE,20X,20HCONTROL RMS RESPONSE,/)
1750  FORMAT (1X,1PD15.7,25X,D15.7)
1760  FORMAT (//,5X,50HCOMPENSATOR TRANSFER FUNCTIONS FROM MEAS. TO INPU
     1T,/,5X,52H......................U/Z = -C*(SI-F+G*C+K*H) INV*K...,//)
1770  FORMAT (//,2X,46HSTEADY DISTURBANCE VECTOR....................h..,//
     1,10(1X,1PD12.4/))
1780  FORMAT (//,5X,45HSTEADY STATE VALUES OF STATE VAR. ARE.........,//)
1790  FORMAT (//,5X,47HSTEADY STATE CONTROL IS ........................,/
     1/10(1X,1PD12.4/))
1800  FORMAT (//,5X,49HENTER THE MAGNITUDE OF THE DESTABILIZATION VECTOR
     1,/,8X,47HTO BE ADDED DOWN THE DIAGONAL OF THE "F"-MATRIX,/,8X,18HT
     2O DESTABILIZE IT.,//)
      END
```

```
C=========================================================================
      SUBROUTINE RAPRNT (NMAX,M,N,L,A,IDIM,FMT)
      REAL*8 A(NMAX,N)
      DIMENSION FMT(IDIM)
      NU=L
      DO 20 NL=1,N,L
      IF (NU.GT.N) NU=N
      DO 10 I=1,M
10    WRITE (6,FMT) (A(I,J),J=NL,NU)
      WRITE (6,30)
20    NU=NU+L
      RETURN
30    FORMAT (1X)
      END
```

```
C=======================================================================
      SUBROUTINE RGAIN (M,NS,NC,NCB,WR,WI,VF,GN,W11,TCB,W21,LT,C,CI,CT,M
     1HS,MT)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION WR(M),WI(M),VF(M,M),GN(NS,NS)
      DIMENSION W11(NS,NS),TCB(M,M),W21(NS,NS),LT(NS),MT(NS)
      DIMENSION C(NS),CI(NS),CT(NS,NS)
      K=1
      KP=1
      KN=1
      NRZEV=0
      NCPZEV=0
10    IF (K.GT.M) GO TO 210
C-----------------------------------------------------------------------
C CHECK FOR EIGVAL AT OR NEAR J-OMEGA AXIS TO INCLUDE IN E-L EIGSYS
C  TURN FIRST ONE POSITIVE AND SECOND ONE NEGATIVE
C-----------------------------------------------------------------------
      EIGVR=DABS(WR(K))
      IF (EIGVR.GE.1.D-10) GO TO 60
      IF (WI(K)) 40,20,40
20    NRZEV=NRZEV+1
      IF (NRZEV.GT.1) GO TO 30
      WR(K)=EIGVR
      GO TO 80
30    WR(K)=-EIGVR
      WRITE (6,290)
      GO TO 150
40    NCPZEV=NCPZEV+1
      IF (NCPZEV.GT.1) GO TO 50
      WR(K)=EIGVR
      WR(K+1)=EIGVR
      GO TO 110
50    WR(K)=-EIGVR
      WR(K+1)=-EIGVR
      WRITE (6,300)
      GO TO 180
60    IF (WR(K)) 140,70,70
70    IF (WI(K)) 110,80,110
C---------------EIGENVECTOR FOR REAL EIGENVALUE,POSITIVE---------------
80    IF (NOB.EQ.0) GO TO 100
      DO 90 J=1,M
90    TCB(J,KP)=VF(J,K)
100   KP=KP+1
      K=K+1
      GO TO 10
C-----------EIGENVECTOR FOR COMPLEX EIGENVALUE,POSITIVE REAL PART-------
110   IF (NOB.EQ.0) GO TO 130
      DO 120 J=1,M
      FR=VF(J,K)
      FI=-VF(J,K+1)
      TCB(J,KP)=FR+FI
120   TCB(J,KP+1)=FR-FI
130   KP=KP+2
      K=K+2
      GO TO 10
140   IF (WI(K)) 180,150,180
C------------EIGENVECTOR FOR REAL EIGENVALUE,NEGATIVE REAL PART---------
150   C(KN)=WR(K)
      CI(KN)=WI(K)
      IF (NOB.NE.0) GO TO 170
      KNS=KN+NS
      DO 160 J=1,M
160   TCB(J,KNS)=VF(J,K)
170   KN=KN+1
      K=K+1
      GO TO 10
C-----------EIGENVECTOR FOR COMPLEX EIGENVALUE,NEGATIVE REAL PART------
180   RR=WR(K)
      RI=WI(K)
      C(KN)=RR
      C(KN+1)=RR
      CI(KN)=RI
      CI(KN+1)=-RI
      IF (NOB.NE.0) GO TO 200
      KNS=KN+NS
      DO 190 J=1,M
```

```
      FR=VF(J,K)
      FI=-VF(J,K+1)
      TCB(J,KNS)=FR+FI
190   TCB(J,KNS+1)=FR-FI
200   KN=KN+2
      K=K+2
      GO TO 10
210   CONTINUE
      IF (NOB.NE.0)  GO TO 240
C-------------------------FORMATION OF W11-------------------------------
      DO 220  I=1,NS
      DO 220  J=1,NS
      W11(I,J)=TCB(I,J+NS)
220   CT(I,J)=W11(I,J)
C-------------------------FORMATION OF W21-------------------------------
      DO 230  I=1,NS
      DO 230  J=1,NS
230   W21(I,J)=TCB(I+NS,J+NS)
240   IF (NOB.EQ.0)  GO TO 260
      DO 250  I=1,NS
      DO 250  J=1,NS
      W21(I,J)=-TCB(I,J)
250   W11(I,J)=TCB(I+NS,J)
260   CONTINUE
C----------------------------INVERT W11----------------------------------
      NSQ=NS*NS
      CALL MINV (NSQ,W11,NS,DETC,LT,MT)
C---------------------CALCULATE THE RGAIN MATRIX-------------------------
      DO 270  IL=1,NS
      DO 270  JL=1,NS
      GN(IL,JL)=0.D0
      DO 270  KL=1,NS
270   GN(IL,JL)=GN(IL,JL)+W21(IL,KL)*W11(KL,JL)
      IF (NOB.EQ.0)  RETURN
      DO 280  I=1,NS
      DO 280  J=1,NS
280   CT(I,J)=W11(J,I)
      RETURN
C-----------------------------------------------------------------------
290    FORMAT (1X,51H EULER-LAGRANGE EQUATICNS HAVE A REAL EIGENVALUE AT,
     114H OR NEAR ZERO./)
300    FORMAT (1X,49H EULER-LAGRANGE EQUATICNS HAVE A COMPLEX PAIR OF ,40
     1HEIGENVALUES AT OR NEAR THE J-OMEGA AXIS.)
       END
```

```
C========================================================================
      SUBROUTINE MINV (NSQ,A,N,D,L,M)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(NSQ),L(N),M(N)
      DOUBLE PRECISION A,D,BIGA,HOLD
      NN=N*N
      D=1.0D0
      NK=-N
      DO 180 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
      IF (DABS(BIGA)-DABS(A(IJ))) 10,20,20
10    BIGA=A(IJ)
      L(K)=I
      M(K)=J
20    CONTINUE
C-------------------------------INTERCHANGE ROWS---------------------------
      J=L(K)
      IF (J-K) 50,50,30
30    KI=K-N
      DO 40 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
40    A(JI)=HOLD
C-------------------------------INTERCHANGE COLUMNS------------------------
50    I=M(K)
      IF (I-K) 80,80,60
60    JP=N*(I-1)
      DO 70 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
70    A(JI)=HOLD
C---------------------------DIVIDE COLUMN BY MINUS PIVOT------------------
C-------------------(VALUE OF PIVOT ELEMENT IS CONTAINED IN BIGA)--------
80    IF (BIGA) 100,90,100
90    D=0.0D0
      RETURN
100   DO 120 I=1,N
      IF (I-K) 110,120,110
110   IK=NK+I
      A(IK)=A(IK)/(-BIGA)
120   CONTINUE
C-------------------------------REDUCE MATRIX------------------------------
      DO 150 I=1,N
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 150 J=1,N
      IJ=IJ+N
      IF (I-K) 130,150,130
130   IF (J-K) 140,150,140
140   KJ=IJ-I+K
      A(IJ)=HOLD*A(KJ)+A(IJ)
150   CONTINUE
C------------------------------DIVIDE ROW BY PIVOT-------------------------
      KJ=K-N
      DO 170 J=1,N
      KJ=KJ+N
      IF (J-K) 160,170,160
160   A(KJ)=A(KJ)/BIGA
170   CONTINUE
C-------------------------------PRODUCT OF PIVOTS--------------------------
      D=D*BIGA
C---------------------------REPLACE PIVOT BY RECIPROCAL-------------------
      A(KK)=(1.0D0)/BIGA
```

```
180   CONTINUE
C-----------------------FINAL ROW AND COLUMN INTERCHANGE---------------
      K=N
190   K=(K-1)
      IF (K) 260,260,200
200   I=L(K)
      IF (I-K) 230,230,210
210   JQ=N*(K-1)
      JR=N*(I-1)
      DO 220 J=1,N
      JK=JQ+J
      HOLD=A(JK)
      JI=JR+J
      A(JK)=-A(JI)
220   A(JI)=HOLD
230   J=M(K)
      IF (J-K) 190,190,240
240   KI=K-N
      DO 250 I=1,N
      KI=KI+N
      HOLD=A(KI)
      JI=KI-K+J
      A(KI)=-A(JI)
250   A(JI)=HOLD
      GO TO 190
260   K=0
      RETURN
      END
```

```
C=====================================================================
      SUBROUTINE SCCV (NL,WL,WLI,VL1,VL2,NR,WR,WRI,VR1,VR2,Q,X)
      REAL*8 VL1(NL),VL2(NL),WL(NL,NL),WLI(NL,NL),X(NL,NR),Q(NL,NR),
     1    VR1(NR),VR2(NR),WR(NR,NR),WRI(NR,NR)
      REAL*8 A,B,C,D,K1,K2,K3,K4
10    DO 20 I=1,NL
      DO 20 J=1,NR
      X(I,J)=0.
      DO 20 II=1,NL
20    X(I,J)=X(I,J)+WLI(I,II)*Q(II,J)
      DO 40 I=1,NL
      DO 40 J=1,NR
      Q(I,J)=0.
      DO 30 JJ=1,NR
30    Q(I,J)=Q(I,J)+X(I,JJ)*WRI(J,JJ)
40    CONTINUE
      I=1
50    IF (VL2(I)) 60,110,60
60    J=1
70    IF (VR2(J)) 80,90,80
80    A=VL1(I)+VR1(J)
      B=-2.*VL2(I)*VR2(J)
      C=A**2+VL2(I)**2+VR2(J)**2
      D=C**2-B**2
      K1=A*C/D
      K2=-(VR2(J)*C+VL2(I)*B)/D
      K3=-(VR2(J)*B+VL2(I)*C)/D
      K4=-A*B/D
      I1=I+1
      J1=J+1
      X(I,J)=+K1*Q(I,J)+K2*Q(I,J1)+K3*Q(I1,J)+K4*Q(I1,J1)
      X(I,J1)=-K2*Q(I,J)+K1*Q(I,J1)-K4*Q(I1,J)+K3*Q(I1,J1)
      X(I1,J)=-K3*Q(I,J)-K4*Q(I,J1)+K1*Q(I1,J)+K2*Q(I1,J1)
      X(I1,J1)=+K4*Q(I,J)-K3*Q(I,J1)-K2*Q(I1,J)+K1*Q(I1,J1)
      J=J+2
      GO TO 100
90    A=VR1(J)+VL1(I)
      B=A**2+VL2(I)**2
      K1=A/B
      K2=VL2(I)/B
      X(I,J)=K1*Q(I,J)-K2*Q(I+1,J)
      X(I+1,J)=K2*Q(I,J)+K1*Q(I+1,J)
      J=J+1
100   IF (J.LE.NR) GO TO 70
      I=I+2
      GO TO 160
110   J=1
120   IF (VR2(J)) 130,140,130
130   A=VR1(J)+VL1(I)
      B=A**2+VR2(J)**2
      K1=A/B
      K2=VR2(J)/B
      X(I,J)=K1*Q(I,J)-K2*Q(I,J+1)
      X(I,J+1)=K2*Q(I,J)+K1*Q(I,J+1)
      J=J+2
      GO TO 150
140   X(I,J)=Q(I,J)/(VR1(J)+VL1(I))
      J=J+1
150   IF (J.LE.NR) GO TO 120
      I=I+1
160   IF (I.LE.NL) GO TO 50
      DO 170 I=1,NL
      DO 170 J=1,NR
      Q(I,J)=0.
      DO 170 II=1,NL
170   Q(I,J)=Q(I,J)+WL(I,II)*X(II,J)
      DO 190 I=1,NL
      DO 190 J=1,NR
      X(I,J)=0.
      DO 180 JJ=1,NR
180   X(I,J)=X(I,J)+Q(I,JJ)*WR(J,JJ)
190   CONTINUE
      RETURN
      END
```

```
C======================================================================
      SUBROUTINE MODE (WNORM,G,GNORM,NS,N1,N2,ICON)
C                                                                     =
C   WNORM  TRANSFORMATION MATRIX U OR U-INV                           =
C   NS     NO. OF STATE                                               =
C   NC     NO.  OF INPUTS OR OUTPUTS                                  =
C   ICON  CONTROL FLAG TO INDICATE WHICH TRANSFORMATION               =
C           0 =  MODAL G                                              =
C           1 =  MODAL GAMMA                                          =
C           2 =  MODAL H                                              =
C           3 =  MODAL C                                              =
C           4 =  MODAL K                                              =
C           5 =  CONTROL EIGENVECTOR MATRIX                           =
C           6 =  MEASUREMENT EIGENVECTOR MATRIX                       =
C======================================================================
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION WNORM(NS,NS),G(N1,N2),GNORM(N1,N2)
      DO 10 I=1,N1
      DO 10 J=1,N2
10    GNORM(I,J)=0.
      IPOINT=ICON+1
      GO TO (20,20,90,90,20,90,90), IPOINT
20    DO 30 J=1,N2
      DO 30 I=1,NS
      DO 30 K=1,NS
30    GNORM(I,J)=GNORM(I,J)+WNORM(I,K)*G(K,J)
      GO TO (40,70,90,90,80), IPOINT
40    WRITE (6,170)
50    DO 60 I=1,NS
60    WRITE (6,230)  (GNORM(I,J),J=1,N2)
      RETURN
70    WRITE (6,180)
      GO TO 50
80    WRITE (6,240)
      GO TO 50
90    DO 100 J=1,NS
      DO 100 I=1,N1
      DO 100 K=1,NS
100   GNORM(I,J)=GNORM(I,J)+G(I,K)*WNORM(K,J)
      GO TO (110,110,110,120,110,130,140), IPOINT
110   WRITE (6,190)
      GO TO 150
120   WRITE (6,200)
      GO TO 150
130   WRITE (6,210)
      GO TO 150
140   WRITE (6,220)
150   DO 160 I=1,N1
160   WRITE (6,230)  (GNORM(I,J),J=1,NS)
      RETURN
C----------------------------------------------------------------------
170    FORMAT (//,5X,45HMODAL CONTROL DISTRIBUTION MATRIX......TI*G..,//)
180    FORMAT (//,5X,50HMODAL PROCESS NOISE DISTRIBUTION MATRIX...TI*GAM.
     1.,//)
190    FORMAT (//,5X,45HMODAL MEASUREMENT SCALING MATRIX...H(BAR)*T..,//)
200    FORMAT (//,5X,45HTHE MODAL CONTROL GAINS..................C*T..,//)
210    FORMAT (//,5X,45HCONTROL EIGENVECTOR MATRIX..............C*M..,//)
220    FORMAT (//,5X,45HMEASUREMENT EIGENVECTOR MATRIX.....H(BAR)*M..,//)
230    FORMAT (1X,(2X,1P6D14.6))
240    FORMAT (//,5X,45HMODAL FILTER STEADY STATE GAINS........TI*K..,//)
       END
```

```
C=====================================================================
      SUBROUTINE CNORM (WZ,WY,VEC,NS,IWRITE,NSQ,DDD,D1,D2,WNORM,WNORMI,H
     1O,CM,N1,N2)
C                                                                    =
C           WZ(I)       REAL PART OF I-TH EIGENVALUE                 =
C                                                                    =
C           WY(I)       COMPLEX PART OF I-TH EIGENVALUE              =
C                                                                    =
C           VEC         MATRIX OF RIGHT EIGENVECTORS STORED IN REAL FORM  =
C                        FROM HQR2                                   =
C           NS          NO. OF STATES                                =
C                                                                    =
C           IWRITE      FLAG TO CONTROL FORMATS FOR DIFFERENT EIGHENSYSTEMS=
C                                                                    =
C           WNORM       NORMALIZED MATRIX U OF RIGHT EIGENVECTORS STORED  =
C                        BY COLUMNS IN REAL FORM                     =
C           WNORMI      U-INVERSE 2*CONGUGATE OF LEFT EIGENVECTORS   =
C                          STORED BY ROW IN REAL FORM                =
C           NSQ,DDD,D1,D2 - ARGUMENTS PASSED TO MINV                 =
C=====================================================================
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 FIELD,COMMA,SEMCOL,RIGHT,FMT
      DIMENSION WZ(NS),WY(NS),VEC(NS,NS),WNORM(NS,NS),WNORMI(NS,NS),STOR
     1E(6),D1(NS),D2(NS),FMT(14),HO(N1,N2),CM(N1,N2)
      DATA FIELD/5HE12.5/,COMMA/5H,',',/,SEMCOL/5H,':',/,RIGHT/1H)/,FMT/
     16H(1X,1P,13*1H /,SEMEND/4H,':'/
C-----------NORMALIZE COMPLEX EIGENVECTORS BY LARGEST ELEMENT------------
      KK=0
      LB=0
      LC=0
      DO 50 K=1,NS
      IF (KK.EQ.1) GO TO 40
      IF (DABS(WY(K)).LT.1.D-10) GO TO 50
      LC=LC+1
      EMAX=0.D0
      DO 20 I=1,NS
      CMOD=VEC(I,K)**2+VEC(I,K+1)**2
      IF (CMOD-EMAX) 20,10,10
10    EMAX=CMOD
      M=I
20    CONTINUE
      VMR=VEC(M,K)
      VMI=VEC(M,K+1)
      DO 30 I=1,NS
      VR=VEC(I,K)
      VI=VEC(I,K+1)
      VECRN=(VR*VMR+VI*VMI)/EMAX
      VECIN=(-VR*VMI+VI*VMR)/EMAX
      WNORM(I,K)=VECRN
      WNORM(I,K+1)=VECIN
30    CONTINUE
      KK=1
      GO TO 50
40    KK=0
50    CONTINUE
C------------NORMALIZE REAL EIGENVECTORS BY THE TOTAL LENGTH------------
      DO 80 K=1,NS
      IF (DABS(WY(K)).GE.1.D-10) GO TO 80
      LR=LR+1
      REMOD=0.D0
      DO 60 I=1,NS
60    REMOD=VEC(I,K)**2+REMOD
      RMOD=DSQRT(REMOD)
      DO 70 I=1,NS
      RVEC=VEC(I,K)/RMOD
      WNORM(I,K)=RVEC
70    CONTINUE
80    CONTINUE
      GO TO (90,100,110,120,130), IWRITE
90    WRITE (6,320)
      GO TO 140
100   WRITE (6,330)
      GO TO 140
110   WRITE (6,340)
      GO TO 140
120   WRITE (6,350)
```

```
      GO TO 140
130   WRITE (6,360)
140   KK=0
      NPRTW=0
      NFMTW=1
      DO 180 I=1,NS
      IF (KK.EQ.1) GO TO 170
      IF (DABS(WY(I)).GT.1.D-10) KK=1
C----PRINT OUT NO MORE THAN 6 WORDS, NOT SEPARATING COMPLEX EIGVAL------
      IF (NPRTW.LT.5.OR.(NPRTW.EQ.5.AND.KK.EQ.0)) GO TO 150
      FMT(NFMTW+1)=RIGHT
      WRITE (6,FMT) (STORE(J),J=1,NPRTW)
      NPRTW=0
      NFMTW=1
150   NPRTW=NPRTW+1
      NFMTW=NFMTW+1
      IF (KK.EQ.1) GO TO 160
      STORE(NPRTW)=WZ(I)
      FMT(NFMTW)=FIELD
      NFMTW=NFMTW+1
      FMT(NFMTW)=SEMCOL
      GO TO 180
160   STORE(NPRTW)=WZ(I)
      FMT(NFMTW)=FIELD
      FMT(NFMTW+1)=COMMA
      STORE(NPRTW+1)=WY(I)
      FMT(NFMTW+2)=FIELD
      FMT(NFMTW+3)=SEMCOL
      NFMTW=NFMTW+3
      NPRTW=NPRTW+1
      GO TO 180
170   KK=0
180   CONTINUE
      FMT(NFMTW)=SEMEND
      FMT(NFMTW+1)=RIGHT
      WRITE (6,FMT) (STORE(J),J=1,NPRTW)
      IF (IWRITE.NE.1) GO TO 190
      WRITE (6,370)
      GO TO 200
190   WRITE (6,380)
200   CALL RAPRNT (NS,NS,NS,6,WNORM,4,'(6(1X,1PD13.6))')
      GO TO (230,210,210,220,220), IWRITE
210   CALL MODE (WNORM,HO,CM,NS,N1,N2,5)
      GO TO 230
220   CALL MODE (WNORM,HO,CM,NS,N1,N2,6)
230   GO TO (240,250,260,270,280), IWRITE
240   WRITE (6,390)
      GO TO 290
250   WRITE (6,400)
      GO TO 290
260   WRITE (6,410)
      GO TO 290
270   WRITE (6,420)
      GO TO 290
280   WRITE (6,430)
C-------------------SAVE U-INVERSE OPEN LOOP IN WNORMI------------------
290   IF (IWRITE .GT. 1) GO TO 310
      DO 300 I=1,NS
      DO 300 J=1,NS
300   WNORMI(I,J)=WNORM(I,J)
      CALL MINV (NSQ,WNORMI,NS,DDD,D1,D2)
      CALL RAPRNT (NS,NS,NS,6,WNORMI,4,'(6(1X,1PD13.6))')
      RETURN
310   CALL MINV (NSQ,WNORM,NS,DDD,D1,D2)
      CALL RAPRNT (NS,NS,NS,6,WNORM,4,'(6(1X,1PD13.6))')
      RETURN
C----------------------------------------------------------------------
320   FORMAT (//1X,42HOPEN LOOP EIGENVALUES..........DET(SI-F)..,//)
330   FORMAT (//1X,46HC-LOOP OPTIMAL REG. E-VALUES...DET(SI-F+G*C)..,//)
340   FORMAT (//1X,46HC-LOOP SUBOPT. REG. E-VALUES...DET(SI-F+G*C)..,//)
350   FORMAT (//1X,46HC-LOOP OPTIMAL EST. E-VALUES...DET(SI-F+K*H)..,//)
360   FORMAT (//1X,46HC-LOOP SUBOPT. EST. E-VALUES...DET(SI-F+K*H)..,//)
370   FORMAT (//1X,46HOPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....,//)
380   FORMAT (//1X,46HC-LOOP RIGHT EIGENVECTOR MATRIX..........M....,//)
390   FORMAT (//1X,46HOPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..,//)
400   FORMAT (//1X,46HC-LOOP OPT. REG. LEFT E-VECTOR MATRIX..M-INV..,//)
```

```
410    FORMAT (//1X,46HC-LOOP SUBOPT-REG. LEFT E-VECTOR MATRIX..M-INV,//)
420    FORMAT (//1X,46HC-LOOP OPT. FILTER LEFT E-VECTOR MATRIX..M-INV,//)
430    FORMAT (//1X,51HC-LOOP SUBOPT. FILTER LEFT E-VECTOR MATRIX..M-INV.
      1.,//)
       END
```

```
C======================================================================
      SUBROUTINE TF (N,NM,NSQ,A,AA,M,B,BM,L,C,CM,IFDFW,D,BB,CC,CP,
     1     EVR,EVI,PR,PI,SC,JCF,RES,D1,D2,DDD,EPS,ITF,ITFX)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(N,N),AA(N,N),B(N,M),BM(N,M),C(L,N),CM(L,N),D(L,M),BB(N
     1),CC(N),CP(N),EVR(N),EVI(N),PR(N),PI(N),SC(N,N),JCF(N),RES(N),D1(N
     2),D2(N)
C--SAVE COMPUTATION ON OL AND CL SYS WITH MODAL WORK DONE IN OPTSYS-----
      IF (ITFX .EQ. 1) GO TO 50
      IF (ITFX .EQ. 2) GO TO 10
      CALL POLES (N,NM,A,AA,M,B,L,C,PR,PI,D1,D2,JCF,SC)
C-----------------COMPUTE MODAL MATRICES FOR RESIDUES--------------------
10    DO 20 I=1,N
      DO 20 J=1,N
20    AA(I,J)=SC(I,J)
      DO 30 I=1,L
      DO 30 J=1,N
      CM(I,J)=0.D0
      DO 30 K=1,N
30    CM(I,J)=CM(I,J)+C(I,K)*AA(K,J)
      CALL MINV (NSQ,AA,N,DDD,D1,D2)
      DO 40 I=1,N
      DO 40 J=1,M
      BM(I,J)=0.D0
      DO 40 K=1,N
40    BM(I,J)=BM(I,J)+AA(I,K)*B(K,J)
50    CONTINUE
      DO 60 I=1,M
      DO 60 J=1,L
      IF (ITF .NE. 3) CALL ZEROS (I,J,IFDFW,N,NM,A,AA,M,B,L,C,D,BB,CC,CP
     1,EVR,EVI,D1,D2,EPS)
      IF (ITF .NE. 2) CALL RESID (I,J,N,JCF,M,BM,L,CM,PR,PI,RES,BB,CC,1)
60    CONTINUE
      RETURN
      END
```

```
C=======================================================================
      SUBROUTINE POLES (N,NM,A,AA,M,B,L,C,EVR,EVI,D1,D2,JCF,SC)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(N,N),AA(N,N),B(N,M),C(L,N),EVR(N),EVI(N),D1(N),D2(N),J
     1CF(N),SC(N,N)
      DO 10 I=1,N
      DO 10 J=1,N
10    AA(I,J)=A(I,J)
      CALL BALANC (NM,N,AA,LOW,IHIGH,D1)
      CALL ORTHES (NM,N,LOW,IHIGH,AA,D2)
      CALL ORTRAN (NM,N,LOW,IHIGH,AA,D2,SC)
      CALL HQR2 (NM,N,LOW,IHIGH,AA,EVR,EVI,SC,IERR)
      IF (IERR .NE. 0) GO TO 30
      CALL BALBAK (NM,N,LOW,IHIGH,D1,N,SC)
      WRITE (6,40)
      DO 20 I=1,N
20    WRITE (6,50) EVR(I),EVI(I)
      RETURN
30    WRITE (6,60)
      RETURN
C-----------------------------------------------------------------------
40    FORMAT (///,28H TF DENOMINATOR EIGENVALUES:,/)
50    FORMAT (/,2X,3H   (,F13.6,4H) +J(,F13.6,1H))
60    FORMAT (35H FAILURE IN HQR2, CALCULATING POLES)
      END
```

```
C===========================================================================
      SUBROUTINE ZEROS (K1,K2,IFDFW,N,NM,A,AA,M,B,L,C,D,BB,CC,CP,EVR,EVI
     1,     D1,D2,EPS)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(N,N),AA(N,N),B(N,M),C(L,N),D(L,M),BB(N),CC(N),CP(N),EV
     1R(N),EVI(N),D1(N),D2(N)
      DOUBLE PRECISION SCL,DABS
      DO 10 I=1,N
      BB(I)=B(I,K1)
      CC(I)=C(K2,I)
      DO 10 J=1,N
10    AA(I,J)=A(I,J)
      WRITE (6,90) K1,K2
      IF (IFDFW .EQ. 0) GO TO 20
      H=D(K2,K1)
      IF (DABS(H).LE.EPS) GO TO 20
      JJ=N
      GO TO 50
20    NN=N-1
      DO 30 I=1,NN
      H=SCL(N,BB,CC)
      CALL CCOMP (N,NM,AA,CC,CP)
      IF (DABS(H).GT.EPS) GO TO 40
30    CONTINUE
      H=SCL(N,BB,CC)
      WRITE (6,100) H
      GO TO 70
40    JJ=N-I
50    WRITE (6,110) JJ,H
      CALL ACOMP (N,NM,AA,BB,CC,H)
      CALL BALANC (NM,N,AA,LOW,IHIGH,D1)
      CALL ORTHES (NM,N,LOW,IHIGH,AA,D2)
      CALL HQR (NM,N,LOW,IHIGH,AA,EVR,EVI,IERR)
      IF (IERR .NE. 0) GO TO 80
      WRITE (6,120)
      DO 60 I=1,N
60    WRITE (6,130) EVR(I),EVI(I)
70    RETURN
80    WRITE (5,140)
      RETURN
C---------------------------------------------------------------------------
90    FORMAT (///,17H TF FOR INPUT NO.,I3,15H AND OUTPUT NO.,I3,1H:)
100   FORMAT (//,5X,27HNO FINITE ZEROS.  TF GAIN =,E12.4)
110   FORMAT (/,3X,20HORDER OF NUMERATOR =,I3,9X,9HTF GAIN =,E12.4)
120   FORMAT (/,3X,57HNUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO V
     1ALUES):)
130   FORMAT (/,4X,1H(,F13.6,4H)+J(,F13.6,1H))
140   FORMAT (52H FAILURE IN HQR CALCULATING TRANSFER FUNCTION ZEROES)
      END
```

```
C=======================================================================
      SUBROUTINE ACOMP (N,NM,A,B,C,H)
      REAL*8 A,B,C,H
      DIMENSION A(NM,N),B(N),C(N)
      DO 10 I=1,N
      DO 10 J=1,N
10    A(I,J)=A(I,J)-B(I)*C(J)/H
      RETURN
      END
```

```
C=========================================================================
      SUBROUTINE CCCMP (N,NM,A,C,CC)
      REAL*8 A,C,CC
      DIMENSION A(NM,N),C(N),CC(N)
      DO 10 I=1,N
      CC(I)=0.
      DO 10 J=1,N
10    CC(I)=CC(I)+C(J)*A(J,I)
      DO 20 I=1,N
20    C(I)=CC(I)
      RETURN
      END
```

```
C=========================================================================
      FUNCTION SCL (N,B,C)
      REAL*8 B,C,SCL
      DIMENSION B(N),C(N)
      SCL=0.
      DO 10 I=1,N
10    SCL=SCL+C(I)*B(I)
      RETURN
      END
```

```
C=========================================================================
      SUBROUTINE RESID (K1,K2,N,JCF,M,BM,L,CM,PR,PI,RES,BB,CC,IPT)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION JCF(N),BM(N,M),CM(L,N),PR(N),PI(N),RES(N),BB(N),CC(N),PR
     1T(4)
      DATA SN/8H*SIN(B*T/,R1/8H        */,R2/8HEXP(A*T)/,ED/1H)/
      DATA ZERO/0.D0/,T1/4H*T**/,BLANK/8H        /,CS/8H*COS(B*T/
C--------------TEMPORARY MOD TILL JCF IS CALCULATED--------------------
      DO 10 I=1,N
10    JCF(I)=0
C-----------------------TEMPORARY MOD-----------------------------------
      IF (IPT .EQ. 1) WRITE (6,170)
      DO 20 I=1,N
      BB(I)=BM(I,K1)
20    CC(I)=CM(K2,I)
C----------------------LOOP THROUGH THE POLES---------------------------
      I=0
30    I=I+1
      IF (I .GT. N) GO TO 160
      IF (JCF(I) .EQ. 1) GO TO 60
      IF (DABS(PI(I)) .LT. 1.D-10) GO TO 50
C--------COMPUTE SIMPLE COMPLEX POLE RESIDUES AND PRINT BOTH-----------
      RES(I)=CC(I)*BB(I)+CC(I+1)*BB(I+1)
      RES(I+1)=CC(I)*BB(I+1)-CC(I+1)*BB(I)
      IF (IPT .EQ. 0) GO TO 40
      PRT(1)=BLANK
      PRT(2)=R2
      IF (PR(I) .EQ. 0.D0) PRT(2)=BLANK
      PRT(3)=CS
      PRT(4)=ED
      WRITE (6,180) PR(I),PI(I),RES(I),(PRT(J),J=1,4)
      I=I+1
      PRT(3)=SN
      WRITE (6,180) PR(I),PI(I),RES(I),(PRT(J),J=1,4)
      GO TO 30
40    I=I+1
      GO TO 30
50    CONTINUE
C---------------COMPUTE SIMPLE REAL POLE RESIDUE-----------------------
      RES(I)=CC(I)*BB(I)
      IF (IPT .EQ. 0) GO TO 30
      PRT(1)=R1
      PRT(2)=R2
      PRT(3)=BLANK
      PRT(4)=BLANK
      WRITE (6,180) PR(I),PI(I),RES(I),(PRT(J),J=1,4)
      GO TO 30
C---------LOOK AHEAD TO DETERMINE SIZE OF THE JORDAN BLOCK-------------
60    K=1
      KT=N-I
      DO 70 J=I,KT
      IF (JCF(J) .EQ. 0) GO TO 80
70    K=K+1
80    CONTINUE
      IF (DABS(PI(I)) .LT. 1.D-10) GO TO 110
C--------COMPUTE REPEATED COMPLEX POLE AND PRINT OUT ALL FOUR----------
      K=1
      RES(I)=CC(I)*BB(I)+CC(I+1)*BB(I+1)+CC(I+2)*BB(I+2)+CC(I+3)*BB(I+3)
      RES(I+1)=CC(I)*BB(I+1)-CC(I+1)*BB(I)+CC(I+2)*BB(I+3)-CC(I+3)*BB(I+
     12)
      RES(I+2)=CC(I)*BB(I+3)+CC(I+1)*BB(I+2)
      RES(I+3)=CC(I)*BB(I+3)-CC(I+1)*BB(I+2)
      IF (IPT .EQ. 0) GO TO 100
      PRT(1)=R1
      PRT(2)=R2
      IF (DABS(PR(I)) .GT. 1.D-10) GO TO 90
      PRT(1)=BLANK
      PRT(2)=BLANK
90    PRT(3)=CS
      PRT(4)=ED
      WRITE (6,180) PR(I),PI(I),RES(I),(PRT(J),J=1,4)
      PRT(3)=SN
      I=I+1
      WRITE (6,180) PR(I),PI(I),RES(I),(PRT(J),J=1,4)
      PRT(1)=T1
      PRT(2)=R2
```

```
      IF (DABS(PR(I)) .LT. 1.D-10) PRT(2)=BLANK
      PRT(3)=CS
      I=I+1
      WRITE (6,190) PR(I),PI(I),RES(I),PRT(1),K,(PRT(J),J=2,4)
      PRT(3)=SN
      I=I+1
      WRITE (6,190) PR(I),PI(I),RES(I),PRT(1),K,(PRT(J),J=2,4)
      GO TO 30
100   I=I+3
      GO TO 30
C----COMPUTE REPEATED REAL POLE RESIDUE AND PRINT OUT ALL K OF THEM-----
110   CONTINUE
      KT=I+K-1
      NN=0
      DO 130 J=I,KT
      NN=NN+1
      RES(J)=ZERO
      DO 120 JJ=J,KT
120   RES(J)=RES(J)+EB(JJ)*CC(JJ-NN+1)
130   CONTINUE
      IF (IPT .EQ. 0) GO TO 150
      NN=0
      PRT(1)=T1
      PRT(2)=R2
      PRT(3)=BLANK
      PRT(4)=BLANK
      DO 140 J=I,KT
      WRITE (6,190) PR(J),PI(J),RES(J),PRT(1),NN,(PRT(JJ),JJ=2,4)
140   NN=NN+1
      GO TO 30
150   I=KT
      GO TO 30
160   CONTINUE
      RETURN
C-----------------------------------------------------------------------
170    FORMAT (//,3X,22HRESIDUES AT THE POLES:/,T16,9HP O L E S,T41,15HR
     1E S I D U E S,/,T9,7HREAL(A),T26,7HIMAG(B))
180    FORMAT (/,4X,1H(,F13.6,4H)+J(,F13.6,1H),4X,1H(,F13.6,1H),3A8,A1)
190    FORMAT (/,4X,1H(,F13.6,4H)+J(,F13.6,1H),4X,1H(,F13.6,1H),A4,I2,2X,
     12A8,A1)
       END
```

```
C=======================================================================
      SUBROUTINE BALANC (NM,N,A,LOW,IGH,SCALE)
      INTEGER I,J,K,L,M,N,JJ,NM,IGH,LOW,IEXC
      REAL*8 A(NM,N),SCALE(N)
      REAL*8 C,F,G,R,S,B2,RADIX
      REAL*8 DABS
      LOGICAL NOCONV
      DATA RADIX/Z4210000000000000/
C-----------------------------------------------------------------------
      B2=RADIX*RADIX
      K=1
      L=N
      GO TO 60
C------------IN-LINE PROCEDURE FOR ROW AND COLUMN EXCHANGE------------
10    SCALE(M)=J
      IF (J .EQ. M) GO TO 40
      DO 20 I=1,L
      F=A(I,J)
      A(I,J)=A(I,M)
      A(I,M)=F
20    CONTINUE
      DO 30 I=K,N
      F=A(J,I)
      A(J,I)=A(M,I)
      A(M,I)=F
30    CONTINUE
40    GO TO (50,90), IEXC
C-----SEARCH FOR ROWS ISOLATING AN EIGENVALUE AND PUSH THEM DOWN--------
50    IF (L .EQ. 1) GO TO 230
      L=L-1
60    DO 80 JJ=1,L
      J=L+1-JJ
      DO 70 I=1,L
      IF (I .EQ. J) GO TO 70
      IF (A(J,I) .NE. 0.0D0) GO TO 80
70    CONTINUE
      M=L
      IEXC=1
      GO TO 10
80    CONTINUE
      GO TO 100
C-------SEARCH FOR COLUMNS ISOLATING AN EIGENVALUE AND PUSH THEM LEFT---
90    K=K+1
100   DO 120 J=K,L
      DO 110 I=K,L
      IF (I .EQ. J) GO TO 110
      IF (A(I,J) .NE. 0.0D0) GO TO 120
110   CONTINUE
      M=K
      IEXC=2
      GO TO 10
120   CONTINUE
C----------------NOW BALANCE THE SUBMATRIX IN ROWS K TO L--------------
      DO 130 I=K,L
130   SCALE(I)=1.0D0
C----------------ITERATIVE LOOP FOR NORM REDUCTION----------------------
140   NOCONV=.FALSE.
      DO 220 I=K,L
      C=0.0D0
      R=0.0D0
      DO 150 J=K,L
      IF (J .EQ. I) GO TO 150
      C=C+DABS(A(J,I))
      R=R+DABS(A(I,J))
150   CONTINUE
C----------------GUARD AGAINST ZERO C OR R DUE TO UNDERFLOW-------------
      IF (C .EQ. 0.0D0 .OR. R .EQ. 0.0D0) GO TO 220
      G=R/RADIX
      F=1.0D0
      S=C+R
160   IF (C .GE. G) GO TO 170
      F=F*RADIX
      C=C*B2
      GO TO 160
170   G=R*RADIX
180   IF (C .LT. G) GO TO 190
```

```
      F=F/RADIX
      C=C/B2
      GO TO 180
C-----------------------------------NOW BALANCE------------------------------
190   IF ((C + R) / F .GE. 0.95D0 * S) GO TO 220
      G=1.0D0/F
      SCALE(I)=SCALE(I)*F
      NOCONV=.TRUE.
      DO 200 J=K,N
200   A(I,J)=A(I,J)*G
      DO 210 J=1,L
210   A(J,I)=A(J,I)*F
220   CONTINUE
      IF (NOCONV) GO TO 140
230   LOW=K
      IGH=L
      RETURN
      END
```

```
C=========================================================================
      SUBROUTINE ORTHES (NM,N,LOW,IGH,A,ORT)
      INTEGER I,J,M,N,II,JJ,LA,MP,NM,IGH,KP1,LOW
      REAL*8 A(NM,N),ORT(IGH)
      REAL*8 F,G,H,SCALE
      REAL*8 DSQRT,DABS,DSIGN
      LA=IGH-1
      KP1=LOW+1
      IF (LA .LT. KP1) GO TO 100
      DO 90 M=KP1,LA
      H=0.0D0
      ORT(M)=0.0D0
      SCALE=0.0D0
C----------------SCALE COLUMN (ALGOL TOL THEN NOT NEEDED)---------------
      DO 10 I=M,IGH
10    SCALE=SCALE+DABS(A(I,M-1))
      IF (SCALE .EQ. 0.0D0) GO TO 90
      MP=M+IGH
      DO 20 II=M,IGH
      I=MP-II
      ORT(I)=A(I,M-1)/SCALE
      H=H+ORT(I)*ORT(I)
20    CONTINUE
      G=-DSIGN(DSQRT(H),ORT(M))
      H=H-ORT(M)*G
      ORT(M)=ORT(M)-G
C--------------------------FORM (I-(U*UT)/H) * A-------------------------
      DO 50 J=M,N
      F=0.0D0
      DO 30 II=M,IGH
      I=MP-II
      F=F+ORT(I)*A(I,J)
30    CONTINUE
      F=F/H
      DO 40 I=M,IGH
40    A(I,J)=A(I,J)-F*ORT(I)
50    CONTINUE
C-----------------FORM (I-(U*UT)/H)*A*(I-(U*UT)/H)---------------------
      DO 80 I=1,IGH
      F=0.0D0
      DO 60 JJ=M,IGH
      J=MP-JJ
      F=F+ORT(J)*A(I,J)
60    CONTINUE
      F=F/H
      DO 70 J=M,IGH
70    A(I,J)=A(I,J)-F*ORT(J)
80    CONTINUE
      ORT(M)=SCALE*ORT(M)
      A(M,M-1)=SCALE*G
90    CONTINUE
100   RETURN
      END
```

```
C=======================================================================
      SUBROUTINE ORTRAN (NM,N,LOW,IGH,A,ORT,Z)
      INTEGER I,J,N,KL,MM,MP,NM,IGH,LOW,MP1
      REAL*8 A(NM,IGH),ORT(IGH),Z(NM,N)
      REAL*8 G
C---------------INITIALIZE Z TO IDENTITY MATRIX------------------------
      DO 20 I=1,N
      DO 10 J=1,N
10    Z(I,J)=0.0D0
      Z(I,I)=1.0D0
20    CONTINUE
      KL=IGH-LOW-1
      IF (KL .LT. 1) GO TO 80
      DO 70 MM=1,KL
      MP=IGH-MM
      IF (A(MP,MP-1) .EQ. 0.0D0) GO TO 70
      MP1=MP+1
      DO 30 I=MP1,IGH
30    ORT(I)=A(I,MP-1)
      DO 60 J=MP,IGH
      G=0.0D0
      DO 40 I=MP,IGH
40    G=G+ORT(I)*Z(I,J)
C---------------DIVISOR BELOW IS NEGATIVE OF H FORMED IN ORTHES.-------
C---------------DOUBLE DIVISION AVOIDS POSSIBLE UNDERFLOW-------------
      G=(G / ORT(MP))/A(MP,MP-1)
      DO 50 I=MP,IGH
50    Z(I,J)=Z(I,J)+G*ORT(I)
60    CONTINUE
70    CONTINUE
80    RETURN
      END
```

```
C=========================================================================
      SUBROUTINE HQR2 (NM,N,LOW,IGH,H,WR,WI,Z,IERR)
      INTEGER I,J,K,L,M,N,EN,II,JJ,LL,MM,NA,NM,NN,IGH,ITS,LOW,MP2,ENM2,I
     1ERR
      REAL*8 H(NM,N),WR(N),WI(N),Z(NM,N)
      REAL*8 P,Q,R,S,T,W,X,Y,RA,SA,VI,VR,ZZ,NORM,MACHEP
      REAL*8 DSQRT,DABS,DSIGN
      INTEGER MIN0
      LOGICAL NOTLAS
      COMPLEX *16Z3
      COMPLEX *16DCMPLX
      REAL*8 DREAL,DIMAG
C----------STATEMENT FUNCTIONS ENABLE EXTRACTION OF REAL AND IMAGINARY--
C----------PARTS OF DOUBLE PRECISION COMPLEX NUMBERS--------------------
      DREAL(Z3)=Z3
      DIMAG(Z3)=(0.0D0,-1.0D0)*Z3
      DATA MACHEP/Z3410000000000000/
      IERR=0
      NORM=0.0D0
      K=1
C-------STORE ROOTS ISOLATED BY BALANC AND COMPUTE MATRIX NORM----------
      DO 20 I=1,N
      DO 10 J=K,N
10    NORM=NORM+DABS(H(I,J))
      K=I
      IF (I .GE. LOW .AND. I .LE. IGH) GO TO 20
      WR(I)=H(I,I)
      WI(I)=0.0D0
20    CONTINUE
      EN=IGH
      T=0.0D0
C---------------SEARCH FOR NEXT EIGENVALUES-----------------------------
30    IF (EN .LT. LOW) GO TO 290
      ITS=0
      NA=EN-1
      ENM2=NA-1
C---------------LOOK FOR SINGLE SMALL SUB-DIAGONAL ELEMENT-------------
40    DO 50 LL=LOW,EN
      L=EN+LOW-LL
      IF (L .EQ. LOW) GO TO 60
      S=DABS(H(L-1,L-1))+DABS(H(L,L))
      IF (S .EQ. 0.0D0) S=NORM
      IF (DABS(H(L,L-1)) .LE. MACHEP * S) GO TO 60
50    CONTINUE
C------------------------------------FORM SHIFT-------------------------
60    X=H(EN,EN)
      IF (L .EQ. EN) GO TO 220
      Y=H(NA,NA)
      W=H(EN,NA)*H(NA,EN)
      IF (L .EQ. NA) GO TO 230
      IF (ITS .EQ. 30) GO TO 500
      IF (ITS .NE. 10 .AND. ITS .NE. 20) GO TO 80
C---------------------FORM EXCEPTIONAL SHIFT----------------------------
      T=T+X
      DO 70 I=LOW,EN
70    H(I,I)=H(I,I)-X
      S=DABS(H(EN,NA))+DABS(H(NA,ENM2))
      X=0.75D0*S
      Y=X
      W=-0.4375D0*S*S
80    ITS=ITS+1
C---------LOOK FOR TWO CONSECUTIVE SMALL SUB-DIAGONAL ELEMENTS.---------
      DO 90 MM=L,ENM2
      M=ENM2+L-MM
      ZZ=H(M,M)
      R=X-ZZ
      S=Y-ZZ
      P=(R * S - W)/H(M+1,M)+H(M,M+1)
      Q=H(M+1,M+1)-ZZ-R-S
      R=H(M+2,M+1)
      S=DABS(P)+DABS(Q)+DABS(R)
      P=P/S
      Q=Q/S
      R=R/S
      IF (M .EQ. L) GO TO 100
      IF (DABS(H(M,M-1)) * (DABS(Q) + DABS(R)) .LE. MACHEP * DABS(P)
```

```
     1 * (DABS(H(M-1,M-1)) + DABS(ZZ) + DABS(H(M+1,M+1)))) GO TO 100
90    CONTINUE
100   MP2=M+2
      DO 110 I=MP2,EN
      H(I,I-2)=0.0D0
      IF (I .EQ. MP2) GO TO 110
      H(I,I-3)=0.0D0
110   CONTINUE
C--------DOUBLE QR STEP INVOLVING ROWS L TO EN AND COLUMNS M TO EN------
      DO 210 K=M,NA
      NOTLAS=K.NE.NA
      IF (K .EQ. M) GO TO 120
      P=H(K,K-1)
      Q=H(K+1,K-1)
      R=0.0D0
      IF (NOTLAS) R=H(K+2,K-1)
      X=DABS(P)+DABS(Q)+DABS(R)
      IF (X .EQ. 0.0D0) GO TO 210
      P=P/X
      Q=Q/X
      R=R/X
120   S=DSIGN(DSQRT(P*P+Q*Q+R*R),P)
      IF (K .EQ. M) GO TO 130
      H(K,K-1)=-S*X
      GO TO 140
130   IF (L .NE. M) H(K,K-1)=-H(K,K-1)
140   P=P+S
      X=P/S
      Y=Q/S
      ZZ=R/S
      Q=Q/P
      R=R/P
C------------------------------------ROW MODIFICATION---------------------------
      DO 160 J=K,N
      P=H(K,J)+Q*H(K+1,J)
      IF (.NOT. NOTLAS) GO TO 150
      P=P+R*H(K+2,J)
      H(K+2,J)=H(K+2,J)-P*ZZ
150   H(K+1,J)=H(K+1,J)-P*Y
      H(K,J)=H(K,J)-P*X
160   CONTINUE
      J=MIN0(EN,K+3)
C-----------------------------------COLUMN MODIFICATION-------------------------
      DO 180 I=1,J
      P=X*H(I,K)+Y*H(I,K+1)
      IF (.NOT. NOTLAS) GO TO 170
      P=P+ZZ*H(I,K+2)
      H(I,K+2)=H(I,K+2)-P*R
170   H(I,K+1)=H(I,K+1)-P*Q
      H(I,K)=H(I,K)-P
180   CONTINUE
C------------------------------ACCUMULATE TRANSFORMATIONS----------------------
      DO 200 I=LOW,IGH
      P=X*Z(I,K)+Y*Z(I,K+1)
      IF (.NOT. NOTLAS) GO TO 190
      P=P+ZZ*Z(I,K+2)
      Z(I,K+2)=Z(I,K+2)-P*R
190   Z(I,K+1)=Z(I,K+1)-P*Q
      Z(I,K)=Z(I,K)-P
200   CONTINUE
210   CONTINUE
      GO TO 40
C-------------------------------------ONE ROOT FOUND------------------------------
220   H(EN,EN)=X+T
      WR(EN)=H(EN,EN)
      WI(EN)=0.0D0
      EN=NA
      GO TO 30
C-------------------------------------TWO ROOTS FOUND-----------------------------
230   P=(Y - X)/2.0D0
      Q=P*P+W
      ZZ=DSQRT(DABS(Q))
      H(EN,EN)=X+T
      X=H(EN,EN)
      H(NA,NA)=Y+T
      IF (Q .LT. 0.0D0) GO TO 270
```

```
C-----------------------------REAL PAIR-----------------------------------
      ZZ=P+DSIGN(ZZ,P)
      WR(NA)=X+ZZ
      WR(EN)=WR(NA)
      IF (ZZ .NE. 0.0D0) WR(EN)=X-W/ZZ
      WI(NA)=0.0D0
      WI(EN)=0.0D0
      X=H(EN,NA)
      S=DABS(X)+DABS(ZZ)
      P=X/S
      Q=ZZ/S
      R=DSQRT(P*P+Q*Q)
      P=P/R
      Q=Q/R
C----------------------------ROW MODIFICATION-----------------------------
      DO 240 J=NA,N
      ZZ=H(NA,J)
      H(NA,J)=Q*ZZ+P*H(EN,J)
      H(EN,J)=Q*H(EN,J)-P*ZZ
240   CONTINUE
C----------------------------COLUMN MODIFICATION--------------------------
      DO 250 I=1,EN
      ZZ=H(I,NA)
      H(I,NA)=Q*ZZ+P*H(I,EN)
      H(I,EN)=Q*H(I,EN)-P*ZZ
250   CONTINUE
C---------------------------ACCUMULATE TRANSFORMATIONS--------------------
      DO 260 I=LOW,IGH
      ZZ=Z(I,NA)
      Z(I,NA)=Q*ZZ+P*Z(I,EN)
      Z(I,EN)=Q*Z(I,EN)-P*ZZ
260   CONTINUE
      GO TO 280
C---------------------------COMPLEX PAIR----------------------------------
270   WR(NA)=X+P
      WR(EN)=X+P
      WI(NA)=ZZ
      WI(EN)=-ZZ
280   EN=ENM2
      GO TO 30
C----------------ALL ROOTS FOUND.  BACKSUBSTITUTE TO FIND---------------
C----------------VECTORS OF UPPER TRIANGULAR FORM-----------------------
290   IF (NORM .EQ. 0.0D0) GO TO 510
      DO 450 NN=1,N
      EN=N+1-NN
      P=WR(EN)
      Q=WI(EN)
      NA=EN-1
      IF (Q) 370,300,450
C-----------------------------REAL VECTOR---------------------------------
300   M=EN
      H(EN,EN)=1.0D0
      IF (NA .EQ. 0) GO TO 450
      DO 360 II=1,NA
      I=EN-II
      W=H(I,I)-P
      R=H(I,EN)
      IF (M .GT. NA) GO TO 320
      DO 310 J=M,NA
310   R=R+H(I,J)*H(J,EN)
320   IF (WI(I) .GE. 0.0D0) GO TO 330
      ZZ=W
      S=R
      GO TO 360
330   M=I
      IF (WI(I) .NE. 0.0D0) GO TO 340
      T=W
      IF (W .EQ. 0.0D0) T=MACHEP*NORM
      H(I,EN)=-R/T
      GO TO 360
C---------------------------SOLVE REAL EQUATIONS--------------------------
340   X=H(I,I+1)
      Y=H(I+1,I)
      Q=(WR(I) - P)*(WR(I) - P)+WI(I)*WI(I)
      T=(X * S - ZZ * R)/Q
      H(I,EN)=T
```

```
      IF (DABS(X) .LE. DABS(ZZ)) GO TO 350
      H(I+1,EN)=(-R - W * T)/X
      GO TO 360
350   H(I+1,EN)=(-S - Y * T)/ZZ
360   CONTINUE
C------------------------------END REAL VECTOR-----------------------------
      GO TO 450
C------------------------------COMPLEX VECTOR------------------------------
370   M=NA
C----------------LAST VECTOR COMPONENT CHOSEN IMAGINARY SO THAT---------
C----------------EIGENVECTOR MATRIX IS TRIANGULAR------------------------
      IF (DABS(H(EN,NA)) .LE. DABS(H(NA,EN))) GO TO 380
      H(NA,NA)=Q/H(EN,NA)
      H(NA,EN)=-(H(EN,EN) - P)/H(EN,NA)
      GO TO 390
380   Z3=DCMPLX(0.0D0,-H(NA,EN))/DCMPLX(H(NA,NA)-P,Q)
      H(NA,NA)=DREAL(Z3)
      H(NA,EN)=DIMAG(Z3)
390   H(EN,NA)=0.0D0
      H(EN,EN)=1.0D0
      ENM2=NA-1
      IF (ENM2 .EQ. 0) GO TO 450
      DO 440 II=1,ENM2
      I=NA-II
      W=H(I,I)-P
      RA=0.0D0
      SA=H(I,EN)
      DO 400 J=M,NA
      RA=RA+H(I,J)*H(J,NA)
      SA=SA+H(I,J)*H(J,EN)
400   CONTINUE
      IF (WI(I) .GE. 0.0D0) GO TO 410
      ZZ=W
      R=RA
      S=SA
      GO TO 440
410   M=I
      IF (WI(I) .NE. 0.0D0) GO TO 420
      Z3=DCMPLX(-RA,-SA)/DCMPLX(W,Q)
      H(I,NA)=DREAL(Z3)
      H(I,EN)=DIMAG(Z3)
      GO TO 440
C--------------------------SOLVE COMPLEX EQUATIONS-----------------------
420   X=H(I,I+1)
      Y=H(I+1,I)
      VR=(WR(I) - P)*(WR(I) - P)+WI(I)*WI(I)-Q*Q
      VI=(WR(I) - P)*2.0D0*Q
      IF (VR .EQ. 0.0D0 .AND. VI .EQ. 0.0D0) VR=MACHEP*NORM*(DABS(W) + D
     1ABS(Q) + DABS(X) + DABS(Y) + DABS(ZZ))
      Z3=DCMPLX(X*R-ZZ*RA+Q*SA,X*S-ZZ*SA-Q*RA)/DCMPLX(VR,VI)
      H(I,NA)=DREAL(Z3)
      H(I,EN)=DIMAG(Z3)
      IF (DABS(X) .LE. DABS(ZZ) + DABS(Q)) GO TO 430
      H(I+1,NA)=(-RA - W * H(I,NA) + Q * H(I,EN))/X
      H(I+1,EN)=(-SA - W * H(I,EN) - Q * H(I,NA))/X
      GO TO 440
430   Z3=DCMPLX(-R-Y*H(I,NA),-S-Y*H(I,EN))/DCMPLX(ZZ,Q)
      H(I+1,NA)=DREAL(Z3)
      H(I+1,EN)=DIMAG(Z3)
440   CONTINUE
C------------------------------END COMPLEX VECTOR--------------------------
450   CONTINUE
C-------------END BACK SUBSTITUTION. VECTORS OF ISOLATED ROOTS---------
      DO 470 I=1,N
      IF (I .GE. LOW .AND. I .LE. IGH) GO TO 470
      DO 460 J=I,N
460   Z(I,J)=H(I,J)
470   CONTINUE
C---------------MULTIPLY BY TRANSFORMATION MATRIX TO GIVE--------------
C---------------VECTORS OF ORIGINAL FULL MATRIX.-------------------------
      DO 490 JJ=LOW,N
      J=N+LOW-JJ
      M=MIN0(J,IGH)
      DO 490 I=LOW,IGH
      ZZ=0.0D0
      DO 480 K=LOW,M
```

```
480    ZZ=ZZ+Z(I,K)*H(K,J)
       Z(I,J)=ZZ
490    CONTINUE
       GO TO 510
C----------------SET ERROR -->NO CONVERGENCE TO AN----------------------
C----------------EIGENVALUE AFTER 30 ITERATIONS-------------------------
500    IERR=EN
510    RETURN
       END
```

```
C=========================================================================
      SUBROUTINE BALBAK (NM,N,LOW,IGH,SCALE,M,Z)
      INTEGER I,J,K,M,N,II,NM,IGH,LOW
      REAL*8 SCALE(N),Z(NM,M),S
      IF (M .EQ. 0) GO TO 60
      IF (IGH .EQ. LOW) GO TO 30
      DO 20 I=LOW,IGH
      S=SCALE(I)
C----------------LEFT HAND EIGENVECTORS ARE BACK TRANSFORMED------------
C----------------IF THE FOREGOING STATEMENT IS REPLACED BY--------------
C----------------S=1.0D0/SCALE(I).-------------------------------------
      DO 10 J=1,M
10    Z(I,J)=Z(I,J)*S
20    CONTINUE
30    DO 50 II=1,N
      I=II
      IF (I .GE. LOW .AND. I .LE. IGH) GO TO 50
      IF (I .LT. LOW) I=LOW-II
      K=SCALE(I)
      IF (K .EQ. I) GO TO 50
      DO 40 J=1,M
      S=Z(I,J)
      Z(I,J)=Z(K,J)
      Z(K,J)=S
40    CONTINUE
50    CONTINUE
60    RETURN
      END
```

```
C=============================================================================
      SUBROUTINE HQR (NM,N,LOW,IGH,H,WR,WI,IERR)
      INTEGER I,J,K,L,M,N,EN,LL,MM,NA,NM,IGH,ITS,LOW,MP2,ENM2,IERR
      REAL*8 H(NM,N),WR(N),WI(N)
      REAL*8 P,Q,R,S,T,W,X,Y,ZZ,NORM,MACHEP
      REAL*8 DSQRT,DABS,DSIGN
      INTEGER MIN0
      LOGICAL NOTLAS
      DATA MACHEP/Z3410000000000000/
      IERR=0
      NORM=0.0D0
      K=1
C--------STORE ROOTS ISOLATED BY BALANC AND COMPUTE MATRIX NORM---------
      DO 20 I=1,N
      DO 10 J=K,N
10    NORM=NORM+DABS(H(I,J))
      K=I
      IF (I .GE. LOW .AND. I .LE. IGH) GO TO 20
      WR(I)=H(I,I)
      WI(I)=0.0D0
20    CONTINUE
      EN=IGH
      T=0.0D0
C-------------------------SEARCH FOR NEXT EIGENVALUES---------------------
30    IF (EN .LT. LOW) GO TO 250
      ITS=0
      NA=EN-1
      ENM2=NA-1
C---------------LOOK FOR SINGLE SMALL SUB-DIAGONAL ELEMENT-------------
40    DO 50 LL=LOW,EN
      L=EN+LOW-LL
      IF (L .EQ. LOW) GO TO 60
      S=DABS(H(L-1,L-1))+DABS(H(L,L))
      IF (S .EQ. 0.0D0) S=NORM
      IF (DABS(H(L,L-1)) .LE. MACHEP * S) GO TO 60
50    CONTINUE
C-------------------------------FORM SHIFT--------------------------------
60    X=H(EN,EN)
      IF (L .EQ. EN) GO TO 200
      Y=H(NA,NA)
      W=H(EN,NA)*H(NA,EN)
      IF (L .EQ. NA) GO TO 210
      IF (ITS .EQ. 30) GO TO 240
      IF (ITS .NE. 10 .AND. ITS .NE. 20) GO TO 80
C-------------------------FORM EXCEPTIONAL SHIFT-----------------------
      T=T+X
      DO 70 I=LOW,EN
70    H(I,I)=H(I,I)-X
      S=DABS(H(EN,NA))+DABS(H(NA,ENM2))
      X=0.75D0*S
      Y=X
      W=-0.4375D0*S*S
80    ITS=ITS+1
C----------LOOK FOR TWO CONSECUTIVE SMALL SUB-DIAGONAL ELEMENTS.--------
      DO 90 MM=L,ENM2
      M=ENM2+L-MM
      ZZ=H(M,M)
      R=X-ZZ
      S=Y-ZZ
      P=(R * S - W)/H(M+1,M)+H(M,M+1)
      Q=H(M+1,M+1)-ZZ-R-S
      R=H(M+2,M+1)
      S=DABS(P)+DABS(Q)+DABS(R)
      P=P/S
      Q=Q/S
      R=R/S
      IF (M .EQ. L) GO TO 100
      IF (DABS(H(M,M-1)) * (DABS(Q) + DABS(R)) .LE. MACHEP * DABS(P)
     1 * (DABS(H(M-1,M-1)) + DABS(ZZ) + DABS(H(M+1,M+1)))) GO TO 100
90    CONTINUE
100   MP2=M+2
      DO 110 I=MP2,EN
      H(I,I-2)=0.0D0
      IF (I .EQ. MP2) GO TO 110
      H(I,I-3)=0.0D0
110   CONTINUE
```

```
C------DOUBLE QR STEP INVOLVING ROWS L TO EN AND COLUMNS M TO EN--------
      DO 190 K=M,NA
      NOTLAS=K.NE.NA
      IF (K .EQ. M)  GO TO 120
      P=H(K,K-1)
      Q=H(K+1,K-1)
      R=0.0D0
      IF (NOTLAS)  R=H(K+2,K-1)
      X=DABS(P)+DABS(Q)+DABS(R)
      IF (X .EQ. 0.0D0)  GO TO 190
      P=P/X
      Q=Q/X
      R=R/X
120   S=DSIGN(DSQRT(P*P+Q*Q+R*R),P)
      IF (K .EQ. M)  GO TO 130
      H(K,K-1)=-S*X
      GO TO 140
130   IF (L .NE. M)  H(K,K-1)=-H(K,K-1)
140   P=P+S
      X=P/S
      Y=Q/S
      ZZ=R/S
      Q=Q/P
      R=R/P
C-----------------------------ROW MODIFICATION---------------------------
      DO 160 J=K,EN
      P=H(K,J)+Q*H(K+1,J)
      IF (.NOT. NOTLAS)  GO TO 150
      P=P+R*H(K+2,J)
      H(K+2,J)=H(K+2,J)-P*ZZ
150   H(K+1,J)=H(K+1,J)-P*Y
      H(K,J)=H(K,J)-P*X
160   CONTINUE
      J=MIN0(EN,K+3)
C-----------------------------COLUMN MODIFICATION------------------------
      DO 180 I=L,J
      P=X*H(I,K)+Y*H(I,K+1)
      IF (.NOT. NOTLAS)  GO TO 170
      P=P+ZZ*H(I,K+2)
      H(I,K+2)=H(I,K+2)-P*R
170   H(I,K+1)=H(I,K+1)-P*Q
      H(I,K)=H(I,K)-P
180   CONTINUE
190   CONTINUE
      GO TO 40
C-----------------------------ONE ROOT FOUND-----------------------------
200   WR(EN)=X+T
      WI(EN)=0.0D0
      EN=NA
      GO TO 30
C-----------------------------TWO ROOTS FOUND----------------------------
210   P=(Y - X)/2.0D0
      Q=P*P+W
      ZZ=DSQRT(DABS(Q))
      X=X+T
      IF (Q .LT. 0.0D0)  GO TO 220
C-----------------------------REAL PAIR----------------------------------
      ZZ=P+DSIGN(ZZ,P)
      WR(NA)=X+ZZ
      WR(EN)=WR(NA)
      IF (ZZ .NE. 0.0D0)  WR(EN)=X-W/ZZ
      WI(NA)=0.0D0
      WI(EN)=0.0D0
      GO TO 230
C-----------------------------COMPLEX PAIR-------------------------------
220   WR(NA)=X+P
      WR(EN)=X+P
      WI(NA)=ZZ
      WI(EN)=-ZZ
230   EN=ENM2
      GO TO 30
C---------------SET ERROR -- NO CONVERGENCE TO AN-----------------------
C---------------EIGENVALUE AFTER 30 ITERATIONS---------------------------
240   IERR=EN
250   RETURN
      END
```

```
C=========================================================================
      SUBROUTINE PSDCAL (N2,NS,FA,X,NC,GW,GV ,C,NO,HY,HU,H,
     1  FBGE,NG,GAM,ACL,F,WR,WI,D1,D2,JCF,RES,Q,R,BB,CC,IYU,
     2  IPSD,INORM)
C=========================================================================
C      =  PSDCAL COMPUTES THE PSD OF OUTPUTS OF CONTROLS OF             =
C      =   A CONTROLLED SYSTEM                                           =
C      =                                                                 =
C      =     IYU= 1      OUTPUT PSD                                      =
C      =        = 2      CONTROL PSD                                     =
C      =        = 3      BOTH OUTPUT AND CONTROL PSD                     =
C      =                                                                 =
C      =     IPSD=1      PSD                                             =
C      =         =2      PSD AND TF RESIDUES                             =
C      =                                                                 =
C      =                                                                 =
C      =     INORM=      1,2,... NG   NORMALIZED BY ITH PROCESS NOISE    =
C      =                 NG+1,... NG+NC NORMALIZED BY ITH MEAS NOISE   =
C=========================================================================
      DOUBLE PRECISION FA,X,GW,GV,C,HY,H,FBGE,GAM,ACL,F,WR,WI,D1,D2,RES,
     1BB,CC,Q,R,PSD,W,DNORM,DN1,EMAX,ELOG,EMOD,DW,ST,OM,RE,AI,HU,DW1
      COMPLEX *16ZD,ZN,ZZ
      DIMENSION FA(N2,N2),X(N2,N2),GW(N2,NG),C(NC,NS),HY(NO,N2),H(NC,NS)
     1,FBGE(NS,NO),GAM(NS,NG),ACL(NS,NS),F(NS,NS),WR(N2),WI(N2),D1(N2),D
     22(N2),RES(N2),Q(NG,NG),R(NO,NC),PSD(30),W(30),BB(N2),CC(N2),GV(N2,
     3NC),HU(NC,N2),DW1(4)
      INTEGER JCF(N2)
      DATA DW1/1.D0,2.D0,5.D0,10.D0/
      IF (IYU .EQ. 0) IYU=1
      IF (INORM .EQ. 0) INORM=1
      IPT=0
      IF (IPSD .GT. 1) IPT=1
      IX=INORM-NG
      IF (IX .GT. 0) WRITE (6,330) IX
      IF (IX .LE. 0) WRITE (6,340) INORM
      NSQ=N2*N2
C---------COMPUTE EIGENSYSTEM OF CONTROLLED SYSTEM; FORM FA-------------
      DO 10 I=1,NS
      DO 10 J=1,NS
      FA(I,J)=ACL(I,J)
10    FA(NS+I,J)=0.D0
      DO 30 I=1,NS
      DO 30 J=1,NS
      ST=0.D0
      DO 20 K=1,NO
20    ST=ST+FBGE(I,K)*H(K,J)
      FA(I,NS+J)=-ST
30    FA(NS+I,NS+J)=F(I,J)-ST
      CALL RAPRNT (N2,N2,N2,9,FA,4,'(9(1X,1PD13.6))')
C-------------------------------DEBUG ABOVE-------------------------------
      CALL BALANC (N2,N2,FA,LOW,IHIGH,D1)
      CALL ORTHES (N2,N2,LOW,IHIGH,FA,D2)
      CALL ORTRAN (N2,N2,LOW,IHIGH,FA,D2,X)
      CALL HQR2 (N2,N2,LOW,IHIGH,FA,WR,WI,X,IERR)
      IF (IERR .NE. 0) GO TO 320
      CALL BALBAK (N2,N2,LOW,IHIGH,D1,N2,X)
      CALL RAPRNT (N2,N2,N2,9,X,4,'(9(1X,1PD13.6))')
C------------DEBUG ABOVE;DETERMINE MODAL MATRICES-------------------------
      IF (IYU .EQ. 1) GO TO 60
C-----------------------------HSUBU---------------------------------------
      DO 50 I=1,NC
      DO 50 J=1,N2
      ST=0.D0
      DO 40 K=1,NS
40    ST=ST-C(I,K)*X(K,J)
50    HU(I,J)=ST
      GO TO 90
C-----------------------------HSUBY---------------------------------------
60    DO 80 I=1,NO
      DO 80 J=1,N2
      ST=0.D0
      DO 70 K=1,NS
70    ST=ST+H(I,K)*X(K,J)-H(I,K)*X(NS+K,J)
80    HY(I,J)=ST
      CALL RAPRNT (NC,NC,N2,9,HY,4,'(9(1X,1PD13.6))')
C-----------------------------DEBUG ABOVE---------------------------------
```

```
90     CALL MINV (NSQ,X,N2,ST,D1,D2)
       CALL RAPRNT (N2,N2,N2,9,X,4,'(9(1X,1PD13.6))')
C-----------------------------DEBUG ABOVE------------------------------------
C-----------------------------GSUBW------------------------------------------
       DO 110 I=1,N2
       DO 110 J=1,NG
       ST=0.0D0
       DO 100 K=1,NS
100    ST=ST-X(I,NS+K)*GAM(K,J)
110    GW(I,J)=ST
       CALL RAPRNT (N2,N2,NG,9,GW,4,'(9(1X,1PD13.6))')
C----------DEBUG ABOVE; USE SELECTED NORMALIZATION---------------------
       IF (INORM .LE. NG) DNORM=1.D0/Q(INORM,INORM)
       IF (INORM .GT. NG) DNORM=1.D0/R(INORM-NG,INORM-NG)
C---------------DETERMINE BANDWIDTH OF CONTROLLED SYSTEM---------------
       EMAX=0.D0
       DO 120 I=1,N2
       EMOD=DABS(WR(I)**2 +WI(I)**2)
       IF (EMOD .GT. EMAX) EMAX=EMOD
120    CONTINUE
       EMOD=DSQRT(EMAX)
       EMOD=2*EMOD
C----------------------ROUND UP TO NEAREST 2,4,5,8,10------------------
       ELOG=DLOG10(EMOD)
       IF (ELOG .LT. 0.D0) IPOW=-IDINT(DABS(ELOG) + 1)
       IF (ELOG .GE. 0.D0) IPOW=IDINT(ELOG)
       EMAX=EMOD*10**(-IPOW)
       IF (EMAX .GT. 2.D0) EMOD=2.D0
       IF (EMAX .GT. 4.D0) EMOD=4.D0
       IF (EMAX .GT. 5.D0) EMOD=5.D0
       IF (EMAX .GT. 8.D0) EMOD=8.D0
       IF (EMAX .GE. 10.D0) EMOD=10.D0
       EMAX=EMOD*10**IPOW
       DW=EMAX/20.D0
C-----------------------ADD 10 POINTS 3 DECADES UP---------------------
       IF (EMOD .LT. 5.D) GO TO 130
       EMAX=1.0D1
       IK=3
       GO TO 140
130    EMAX=5.D0
       IK=2
140    CONTINUE
C-----------------------STORE 30 FREQUENCIES---------------------------
       DO 150 I=1,20
150    W(I)=DW*(I-1)
       DO 160 I=1,3
       IP=20+3*(I-1)
       DO 160 J=1,3
       IX=MOD(IK+J-1,3)+1
       JJ=0
       IF (IK .EQ. 2 .AND. J .GE. 2) JJ=1
       W(IP+J)=DW1(IX)*10**(IPOW+I-1+JJ+IK-2)
160    CONTINUE
       IX=MOD(IK,3)+1
       W(30)=DW1(IX)*10**(IPOW+3 +IK-2)
C------------------------LARGE LOOP THRU OUTPUTS-----------------------
       IF (IYU .EQ. 1) NL=NC
       IF (IYU .EQ. 2) NL=NC
       DO 310 L=1,NL
       DO 170 I=1,30
170    PSD(I)=0.D0
C------------------------LOOP THRU PROCESS NOISE-----------------------
       DO 220 I=1,NG
       DN1=DNORM*Q(I,I)
       IF (IYU .EQ. 1 .AND. IPT .EQ. 1) WRITE (6,350) I,L
       IF (IYU .EQ. 2 .AND. IPT .EQ. 1) WRITE (6,360) I,L
       IF (IYU.EQ.1) CALL RESID (I,L,N2,JCP,NG,GW,NL,HY,WR,WI,
      1RES,BB,CC,IPT)
       IF (IYU.EQ.2) CALL RESID (I,L,N2,JCP,NG,GW,NL,HU,WR,WI,
      1RES,BB,CC,IPT)
       DO 210 K=1,20
       ZZ=DCMPLX(0.D0,0.D0)
       OM=W(K)
       DO 200 II=1,N2
       IF (WI(II)) 200,180,190
180    ZD=DCMPLX(-WR(II),OM-WI(II))
```

```
      ZZ=RES(II)/ZD+ZZ
      GO TO 200
190   RE=WR(II)
      AI=WI(II)
      ZD=DCMPLX(RE**2 + AI**2 - OM**2,-2.D0*RE*OM)
      ZN=DCMPLX(RES(II+1)*AI-RES(II)*RE,RES(II)*OM)
      ZZ=ZZ+ZN/ZD
200   CONTINUE
210   PSD(K)=PSD(K)+DN1*(ZZ*DCONJG(ZZ))
220   CONTINUE
C----------------------------GSUBV------------------------------------
      DO 240 I=1,N2
      DO 240 J=1,NO
      ST=0.D0
      DO 230 K=1,NS
230   ST=ST+X(I,K)*FEGE(K,J)+X(I,NS+K)*FBGE(K,J)
240   GV(I,J)=ST
      CALL RAPRNT (N2,N2,NO,9,GV,4,'(9(1X,1PD13.6))')
C-----------------DEBUG ABOVE, LOOP THRU MEAS NOISE---------------------
      DO 300 I=1,NO
      DN1=DNORM*R(I,I)
      IF (IYU .EQ. 1 .AND. IPT .EQ. 1) WRITE (6,370) I,L
      IF (IYU .EQ. 2 .AND. IPT .EQ. 1) WRITE (6,380) I,L
      IF (IYU.EQ.1) CALL RESID (I,L,N2,JCF,NO,GV,NL,HY,WR,WI,RES,
     1    BB,CC,IPT)
      IF (IYU.EQ.2) CALL RESID (I,L,N2,JCF,NO,GV,NL,HU,WR,WI,RES,
     1    BB,CC,IPT)
      DO 290 K=1,30
      ZZ=DCMPLX(0.D0,0.D0)
      OM=W(K)
      DO 270 II=1,N2
      IF (WI(II)) 270,250,260
250   ZD=DCMPLX(-WR(II),OM-WI(II))
      ZZ=ZZ+RES(II)/ZD
      GO TO 270
260   RE=WR(II)
      AI=WI(II)
      ZD=DCMPLX(RE**2 + AI**2 -OM**2,-2.D0*RE*OM)
      ZN=DCMPLX(RES(II+1)*AI-RES(II)*RE,RES(II)*OM)
      ZZ=ZZ+ZN/ZD
270   CONTINUE
      IF (IYU .EQ. 2 .OR. I .NE. L) GO TO 280
      PSD(K)=PSD(K)+DN1
280   PSD(K)=PSD(K)+DN1*(ZZ*DCONJG(ZZ))
290   CONTINUE
300   CONTINUE
      IF (IYU .EQ. 1) WRITE (6,390) L
      IF (IYU .EQ. 2) WRITE (6,400) L
      WRITE (6,410)  (W(I),PSD(I),I=1,30)
310   CONTINUE
      RETURN
320   CONTINUE
      CALL EREXIT (N2,FA,IERR)
      RETURN
C----------------------------------------------------------------------
330   FORMAT (/,41H SUBSEQUENT PSD IS NORMALIZED BY MEAS NO.,I3)
340   FORMAT (/,50H SUBSEQUENT PSD IS NORMALIZED BY PROCESS NOISE NO.,I3
     1)
350   FORMAT (/38H TRANSFER FUNCTION FROM PROCESS NOISE ,I2,3H TO,13H ME
     1ASUREMENT ,I2)
360   FORMAT (/38H TRANSFER FUNCTION FROM PROCESS NOISE ,I2,3H TO,9H CON
     1TROL ,I2)
370   FORMAT (/36H TRANSFER FUNCTION FROM MEASUREMENT ,I2,16H TO MEASURE
     1MENT ,I2)
380   FORMAT (/36H TRANSFER FUNCTION FROM MEASUREMENT ,I2,12H TO CONTROL
     1 ,I2)
390   FORMAT (/14H PSD OF OUTPUT,I3,32H  FORCED BY ALL NOISE-(RAD FREQ,,
     115HNORMALIZED PSD)/)
400   FORMAT (/15H PSD OF CONTROL,I3,32H  FORCED BY ALL NOISE-(RAD FREQ,
     1,15HNORMALIZED PSD)/)
410   FORMAT (4(1X,1H(,E11.4,1H,,E11.4,1H)))
      END
```

```
C=======================================================================
      SUBROUTINE EREXIT (N,A,IERR)
C     EREXIT RETURNS THE NUMBER OF THE EIGENVALUE WHERE HQR2           =
C     FAILS, THEN STOPS THE PROGRAM.                                   =
C=======================================================================
      INTEGER IERR
      DOUBLE PRECISION A
      DIMENSION A(N,N)
      WRITE (5,10) IERR
      CALL RAPRNT (N,N,N,9,A,4,'(9(1X,1PD13.6))')
      RETURN
10    FORMAT (35H FAILURE IN HQR2 ON EIGENVALUE NO. ,I3)
      END
```

```
C======================================================================
      SUBROUTINE READF (NS,ISAF,BA)
C     INTERACTIVELY ENTERS THE "F" MATRIX ELEMENT BY ELEMENT.         =
C======================================================================
      REAL*8  BA(NS,NS),DUM,ANSR
      INTEGER I,J,K,L,IANS,ISAF
      DATA IY/'Y'/,IZ/'N'/
      IF (ISAF.EQ.1) GO TO 40
      WRITE (5,130)
      DO 20 I=1,NS
      DO 10 J=1,NS
      WRITE (5,120) I,J
      CALL RDREAL (ANSR)
      BA(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C----------------------------------------------------------------------
30    CALL PRTCMS ('CLRSCRN ')
40    CONTINUE
      WRITE (5,140)
      CALL MATPRT (BA,NS,NS)
50    WRITE (5,150)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 60
      GO TO 70
60    WRITE (5,160)
      GO TO 50
70    CONTINUE
      IF (IANS.EQ.IZ) GO TO 110
      IF (IANS.EQ.IY) GO TO 80
80    WRITE (5,170)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,180)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,120) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 100 I=1,NS
      DO 90 J=1,NS
      IF ((I.EQ.K).AND.(J.EQ.L)) BA(I,J)=DUM
90    CONTINUE
100   CONTINUE
      GO TO 30
110   CONTINUE
      CALL PRTCMS ('CLRSCRN ')
      RETURN
C----------------------------------------------------------------------
120    FORMAT (5X,14HTHE ELEMENT F(,I2,1H,,I2,2H)=)
130    FORMAT (/,5X,36HENTER THE SYSTEM MATRIX  "F"-MATRIX ,//,10X,41HDIM
     1ENSION = # STATES  NS  X # STATES  NS )
140    FORMAT (//,15X,33HTHE SYSTEM MATRIX  "F"-MATRIX ...,//)
150    FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
160    FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
170    FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
180    FORMAT (5X,53HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1.)
       END
```

```
C=====================================================================
      SUBROUTINE READH (NO,NS,ISAH,HO)
C     INTERACTIVELY ENTERS THE "H" MATRIX  MEASUREMENT SCALING MATRIX .=
C=====================================================================
      REAL*8  HO(NO,NS),DUM,ANSR
      INTEGER IANS,I,J,K,L,ISAH
      DATA IY/'Y'/,IZ/'N'/
C---------------------------------------------------------------------
C  THIS IS AN EXAMPLE OF ONE POSSIBLE METHOD OF ARRAY GENERATION      =
C  WITHIN THE PROGRAM ITSELF.  FOR VERY LARGE DATA ARRAYS, THIS METHOD =
C  MAY BE PREFERABLE TO SOME USERS OVER INTERACTIVE ENTRY OF EACH     =
C  INDIVIDUAL ELEMENT.                                                =
C---------------------------------------------------------------------
C     DO 2 I=1,11
C        DO 1 J=1,82
C              HO(I,J)   = 0.0D+00
C              HO(1,1)   = 0.11520D+00
C              HO(2,75)  = 0.5730D+02
C              HO(3,74)  = 0.1000D+01
C              HO(4,63)  = 0.5730D+02
C              HO(5,62)  = 0.1000D+01
C              HO(6,76)  = 0.5730D+02
C              HO(7,44)  = 0.5730D+02
C              HO(8,45)  = 0.5730D+02
C              HO(9,46)  = 0.5730D+02
C              HO(10,47) = 0.5730D+02
C              HO(11,48) = 0.5730D+02
C1       CONTINUE
C2    CONTINUE
C     GO TO 90
C3    CONTINUE
C---------------------------------------------------------------------
      IF (ISAH.EQ.1) GO TO 40
      WRITE (5,120)
      DO 20 I=1,NO
      DO 10 J=1,NS
      WRITE (5,110) I,J
      CALL RDREAL (ANSR)
      HO(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C---------------------------------------------------------------------
30    CALL PRTCMS ('CLRSCRN ')
40    CONTINUE
      WRITE (5,130)
      CALL MATPRT (HO,NO,NS)
50    WRITE (5,140)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 60
      GO TO 70
60    WRITE (5,150)
      GO TO 50
70    CONTINUE
      IF (IANS.EQ.IZ) GO TO 100
      WRITE (5,160)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,170)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,110) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 90 I=1,NO
      DO 80 J=1,NS
      IF ((I.EQ.K).AND.(J.EQ.L)) HO(I,J)=DUM
80    CONTINUE
90    CONTINUE
      GO TO 30
100   CONTINUE
      CALL PRTCMS ('CLRSCRN ')
      RETURN
C---------------------------------------------------------------------
110   FORMAT (5X,14HTHE ELEMENT H(,I2,1H,,I2,2H)=)
120   FORMAT (/,5X,50HENTER THE MEASUREMENT SCALING MATRIX  "H"-MATRIX .
     1,//,10X,47HDIMENSION = # OBSERVATIONS  NO  X # STATES  NS )
```

```
130   FORMAT (//,10X,46HTHE MEASUREMENT SCALING MATRIX  "H"-MATRIX ... ,/
     1/)
140   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
150   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
160   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
170   FORMAT (5X,52HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1)
      END
```

```
C=======================================================================
      SUBROUTINE READD (NO,NC,D)
C     ENTERS THE "D" MATRIX  MEASUREMENT FEED-FORWARD DIST. MATRIX .   =
C=======================================================================
      REAL*8  D(NO,NC),DUM,ANSR
      INTEGER IANS,I,J,K,L
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,110)
      DO 20 I=1,NO
      DO 10 J=1,NC
      WRITE (5,100) I,J
      CALL RDREAL (ANSR)
      D(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C-----------------------------------------------------------------------
30    CALL FRTCMS ('CLRSCRN ')
      WRITE (5,120)
      CALL MATPRT (D,NO,NC)
40    WRITE (5,130)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 50
      GO TO 60
50    WRITE (5,140)
      GO TO 40
60    CONTINUE
      IF (IANS.EQ.IZ) GO TO 90
      WRITE (5,150)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,160)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,100) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 80 I=1,NO
      DO 70 J=1,NC
      IF ((I.EQ.K).AND.(J.EQ.L)) D(I,J)=DUM
70    CONTINUE
80    CONTINUE
      GO TO 30
90    CONTINUE
      CALL FRTCMS ('CLRSCRN ')
      RETURN
C-----------------------------------------------------------------------
100   FORMAT (5X,14HTHE ELEMENT D(,I2,1H,,I2,2H)=)
110   FORMAT (/,5X,54HENTER THE MEASUREMENT FEEDTHROUGH MATRIX / FEEDFOR
     1WARD,/,5X,34H DISTRIBUTION MATRIX  "D"-MATRIX .,//,8X,49HDIMENSION
     2 = # OBSERVATIONS  NO  X # CONTROLS  NC )
120   FORMAT (//,5X,50HTHE FEEDFORWARD DISTRIBUTION MATRIX  "D"-MATRIX .
     1.,//)
130   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
140   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
150   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
160   FORMAT (5X,53HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1.)
      END
```

```
C=======================================================================
      SUBROUTINE READG (NS,NC,ISAG,G)
C     INTERACTIVELY ENTERS THE "G" MATRIX  CONTROL DISTRIBUTION MATRIX =
C=======================================================================
      REAL*8   G(NS,NC),DUM,ANSR
      INTEGER IANS,I,J,K,L,ISAG
      DATA IY/'Y'/,IZ/'N'/
      IF (ISAG.EQ.1) GO TO 40
      WRITE (5,120)
      DO 20 I=1,NS
      DO 10 J=1,NC
      WRITE (5,110) I,J
      CALL RDREAL (ANSR)
      G(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C-----------------------------------------------------------------------
30    CALL FRTCMS ('CLRSCRN ')
40    CONTINUE
      WRITE (5,130)
      CALL MATPRT (G,NS,NC)
50    WRITE (5,140)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 60
      GO TO 70
60    WRITE (5,150)
      GO TO 50
70    CONTINUE
      IF (IANS.EQ.IZ) GO TO 100
      WRITE (5,160)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,170)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,110) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 90 I=1,NS
      DO 80 J=1,NC
      IF ((I.EQ.K).AND.(J.EQ.L)) G(I,J)=DUM
80    CONTINUE
90    CONTINUE
      GO TO 30
100   CONTINUE
      CALL FRTCMS ('CLRSCRN ')
      RETURN
C-----------------------------------------------------------------------
110   FORMAT (5X,14HTHE ELEMENT G(,I2,1H,,I2,2H)=)
120   FORMAT (/,5X,51HENTER THE CONTROL DISTRIBUTION MATRIX  "G"-MATRIX
     1.,//,10X,43HDIMENSION = # STATES  NS   X # CONTROLS  NC )
130   FORMAT (//,10X,47HTHE CONTROL DISTRIBUTION MATRIX  "G"-MATRIX ...,
     1//)
140   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
150   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
160   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
170   FORMAT (5X,53HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1.)
      END
```

```
C=====================================================================
      SUBROUTINE READFB (NC,NS,FBGC)
C     ENTERS THE "C" MATRIX   FEEDBACK GAIN CONTROL MATRIX .          =
C=====================================================================
      REAL*8  FBGC(NC,NS),DUM,ANSR
      INTEGER IANS,I,J,K,L
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,110)
      DO 20 I=1,NC
      DO 10 J=1,NS
      WRITE (5,100) I,J
      CALL RDREAL (ANSR)
      FBGC(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C---------------------------------------------------------------------
30    CALL PRTCMS ('CLRSCRN ')
      WRITE (5,120)
      CALL MATPRT (FBGC,NC,NS)
40    WRITE (5,130)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 50
      GO TO 60
50    WRITE (5,140)
      GO TO 40
60    CONTINUE
      IF (IANS.EQ.IZ) GO TO 90
      WRITE (5,150)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,160)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,100) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 80 I=1,NC
      DO 70 J=1,NS
      IF ((I.EQ.K).AND.(J.EQ.L)) FBGC(I,J)=DUM
70    CONTINUE
80    CONTINUE
      GO TO 30
90    CONTINUE
      CALL PRTCMS ('CLRSCRN ')
      RETURN
C---------------------------------------------------------------------
100   FORMAT (5X,14HTHE ELEMENT C(,I2,1H,,I2,2H)=)
110   FORMAT (/,5X,52HENTER THE FEEDBACK GAIN CONTROL MATRIX  "C"-MATRIX
     1 .,//,10X,44HDIMENSION = # CONTROLS  NC  X # STATES  NS .)
120   FORMAT (//,10X,45HTHE FEEDBACK GAIN CONTROL MATRIX  "C"-MATRIX ,//
     1)
130   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
140   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
150   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
160   FORMAT (5X,53HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1.)
      END
```

```
C=======================================================================
      SUBROUTINE READAY (NC,AY)
C     ENTERS THE "A" MATRIX   DIAGONAL OUTPUT COST MATRIX .            =
C=======================================================================
      REAL*8   AY(NO,NC),DUM,ANSR
      INTEGER IANS,I,J,K,L
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,110)
      DO 20 I=1,NO
      DO 10 J=1,NO
      WRITE (5,100) I,J
      CALL RDREAL (ANSR)
      AY(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C-----------------------------------------------------------------------
30    CALL PRTCMS ('CLRSCRN ')
      WRITE (5,120)
      CALL MATPRT (AY,NC,NC)
40    WRITE (5,130)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 50
      GO TO 60
50    WRITE (5,140)
      GO TO 40
60    CONTINUE
      IF (IANS.EQ.IZ) GO TO 90
      WRITE (5,150)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,160)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,100) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 80 I=1,NO
      DO 70 J=1,NO
      IF ((I.EQ.K).AND.(J.EQ.L)) AY(I,J)=DUM
70    CONTINUE
80    CONTINUE
      GO TO 30
90    CONTINUE
      CALL PRTCMS ('CLRSCRN ')
      RETURN
C--------------------------------------------------------------------
100   FORMAT (5X,14HTHE ELEMENT A(,I2,1H,,I2,2H)=)
110   FORMAT (//,5X,54HENTER THE OUTPUT MEASUREMENT COST MATRIX  "A"-MAT
     1RIX .,/,5X,53HDIMENSION = # OBSERVATIONS  NO  X # OBSERVATIONS  NO
     2 )
120   FORMAT (//,5X,50HTHE OUTPUT MEASUREMENT COST MATRIX  "A"-MATRIX ..
     1.,//)
130   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
140   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
150   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
160   FORMAT (5X,53HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1.)
      END
```

```
C=======================================================================
      SUBROUTINE READB (NC,B)
C     ENTERS THE "B" MATRIX  CONTROL COST WEIGHTING MATRIX .           =
C=======================================================================
      REAL*8  B(NC,NC),DUM,ANSR
      INTEGER IANS,I,J,K,L
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,90)
      DO 10 I=1,NC
      DO 10 J=1,NC
      WRITE (5,80) I,J
      CALL RDREAL (ANSR)
10    B(I,J)=ANSR
C-----------------------------------------------------------------------
20    CALL PRTCMS ('CLRSCRN ')
      WRITE (5,100)
      CALL MATPRT (B,NC,NC)
30    WRITE (5,110)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 40
      GO TO 50
40    WRITE (5,120)
      GO TO 30
50    CONTINUE
      IF (IANS.EQ.IZ) GO TO 70
      WRITE (5,130)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,140)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,80) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 60 I=1,NC
      DO 60 J=1,NC
      IF ((I.EQ.K).AND.(J.EQ.L)) B(I,J)=DUM
60    CONTINUE
      GO TO 20
70    CONTINUE
      CALL PRTCMS ('CLRSCRN ')
      RETURN
C-----------------------------------------------------------------------
80    FORMAT (5X,14HTHE ELEMENT B(,I2,1H,,I2,2H)=)
90    FORMAT (/,5X,52HENTER THE CONTROL COST WEIGHTING MATRIX  "B"-MATRI
     1X ,/,10X,45HDIMENSION = # CONTROLS  NC  X # CONTROLS  NC )
100   FORMAT (//,10X,37HTHE CONTROL COST MATRIX..........B...,//)
110   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
120   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
130   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
140   FORMAT (5X,52HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1)
      END
```

```
C=========================================================================
      SUBROUTINE READG2 (NS,NG,IGAM,GAM)
C     ENTERS THE "GAM" MATRIX  PROCESS NOISE DISTRIBUTION MATRIX .     =
C=========================================================================
      REAL*8  GAM(NS,NG),DUM,ANSR
      INTEGER IANS,I,J,K,L,IGAM
      DATA IY/'Y'/,IZ/'N'/
      IF (IGAM.EQ.1) GO TO 40
      WRITE (5,120)
      DO 20 I=1,NS
      DO 10 J=1,NG
      WRITE (5,110)  I,J
      CALL RDREAL (ANSR)
      GAM(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C-------------------------------------------------------------------------
30    CALL FETCMS ('CLRSCRN ')
40    CONTINUE
      WRITE (5,130)
      CALL MATPRT (GAM,NS,NG)
50    WRITE (5,140)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 60
      GO TO 70
60    WRITE (5,150)
      GO TO 50
70    CONTINUE
      IF (IANS.EQ.IZ) GO TO 100
      WRITE (5,160)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,170)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,110)  K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 90 I=1,NS
      DO 80 J=1,NG
      IF ((I.EQ.K).AND.(J.EQ.L)) GAM(I,J)=DUM
80    CONTINUE
90    CONTINUE
      GO TO 30
100   CONTINUE
      CALL FETCMS ('CLRSCRN ')
      RETURN
C-------------------------------------------------------------------------
110   FORMAT (5X,16HTHE ELEMENT GAM(,I2,1H,,I2,2H)=)
120   FORMAT (/,5X,36HENTER THE PROCESS NOISE DISTRIBUTION,/,5X,24HMATRI
     1X  "GAMMA"-MATRIX .,/,2X,56HDIMENSION = # STATES  NS  X # PROCESS
     2NOISE SOURCES  NG )
130   FORMAT (//,10X,37HTHE PROCESS NOISE DISTRIBUTION MATRIX,/,10X,19H
     1"GAMMA"-MATRIX ...,//)
140   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
150   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
160   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
170   FORMAT (5X,53HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1.)
      END
```

```
C=======================================================================
      SUBROUTINE READQ (NG,Q)
C     INTERACTIVELY ENTERS THE "Q" MATRIX  NOISE WEIGHTING MATRIX       =
C=======================================================================
      REAL*8  Q(NG,NG),DUM,ANSR
      INTEGER IANS,I,J,K,L
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,110)
      DO 20 I=1,NG
      DO 10 J=1,NG
      WRITE (5,100) I,J
      CALL RDREAL (ANSR)
      Q(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C-----------------------------------------------------------------------
30    CALL FRTCMS ('CLRSCRN ')
      WRITE (5,120)
      CALL MATPRT (Q,NG,NG)
40    WRITE (5,130)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 50
      GO TO 60
50    WRITE (5,140)
      GO TO 40
60    CONTINUE
      IF (IANS.EQ.IZ) GO TO 90
      WRITE (5,150)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,160)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,100) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 80 I=1,NG
      DO 70 J=1,NG
      IF ((I.EQ.K).AND.(J.EQ.L)) Q(I,J)=DUM
70    CONTINUE
80    CONTINUE
      GO TO 30
90    CONTINUE
      CALL FRTCMS ('CLRSCRN ')
      RETURN
C-----------------------------------------------------------------------
100    FORMAT (5X,14HTHE ELEMENT Q(,I2,1H,,I2,2H)=)
110    FORMAT (//,5X,44HENTER THE PROCESS NOISE PSD WEIGHTING MATRIX,/,5X
     1,12H "Q"MATRIX .,//,5X,42HDIMENSION = # PROCESS NOISE SOURCES  NG
     2 X,/,17X,27H#PROCESS NOISE SOURCES  NG )
120    FORMAT (//,5X,42HTHE PROCESS NOISE WEIGHTING MATRIX.....Q...//)
130    FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
140    FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
150    FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
160    FORMAT (5X,53HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1.)
       END
```

```
C=======================================================================
      SUBROUTINE READR (NO,RC)
C     ENTERS  THE "R" MATRIX  MEASUREMENT NOISE DISTRIBUTION MATRIX .  =
C=======================================================================
      REAL*8  RC(NO,NO),DUM,ANSR
      INTEGER IANS,I,J,K,L
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,90)
      DO 10 I=1,NO
      DO 10 J=1,NO
      WRITE (5,80) I,J
      CALL RDREAL (ANSR)
10    RC(I,J)=ANSR
C-----------------------------------------------------------------------
20    CALL FRTCMS ('CLRSCRN ')
      WRITE (5,100)
      CALL MATPRT (RC,NO,NO)
30    WRITE (5,110)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 40
      GO TO 50
40    WRITE (5,120)
      GO TO 30
50    CONTINUE
      IF (IANS.EQ.IZ) GO TO 70
      WRITE (5,130)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,140)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,80) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 60 I=1,NO
      DO 60 J=1,NO
60    IF ((I.EQ.K).AND.(J.EQ.L)) RC(I,J)=DUM
      GO TO 20
70    CONTINUE
      CALL FRTCMS ('CLRSCRN ')
      RETURN
C-----------------------------------------------------------------------
80     FORMAT (5X,14HTHE ELEMENT R(,I2,1H,,I2,2H)=)
90     FORMAT (/,5X,60HENTER THE MEASUREMENT NOISE DISTRIBUTION MATRIX  "
     1R"MATRIX .,//,5X,53HDIMENSION = # OBSERVATIONS  NO  X # OBSERVATIO
     2NS  NO )
100    FORMAT (//,15X,50HTHE MEASUREMENT NOISE DISTRIBUTION MATRIX.....R.
     1..,//)
110    FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
120    FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
130    FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
140    FORMAT (5X,52HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1)
       END
```

```
C=======================================================================
      SUBROUTINE READFE (NS,NO,FBGE)
C     INTERACTIVELY ENTERS THE "K"  FEEDBACK GAIN ESTIMATOR MATRIX     =
C=======================================================================
      REAL*8  FBGE(NS,NO),DUM,ANSR
      INTEGER IANS,I,J,K,L
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,110)
      DO 20 I=1,NS
      DO 10 J=1,NO
      WRITE (5,100) I,J
      CALL RDREAL (ANSR)
      FBGE(I,J)=ANSR
10    CONTINUE
20    CONTINUE
C-----------------------------------------------------------------------
30    CALL PRTCMS ('CLRSCRN ')
      WRITE (5,120)
      CALL MATPRT (FBGE,NS,NO)
40    WRITE (5,130)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 50
      GO TO 60
50    WRITE (5,140)
      GO TO 40
60    CONTINUE
      IF (IANS.EQ.IZ) GO TO 90
      WRITE (5,150)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,160)
      CALL RDINT (IANS)
      L=IANS
      WRITE (5,100) K,L
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 80 I=1,NS
      DO 70 J=1,NO
      IF ((I.EQ.K).AND.(J.EQ.L)) FBGE(I,J)=DUM
70    CONTINUE
80    CONTINUE
      GO TO 30
90    CONTINUE
      CALL PRTCMS ('CLRSCRN ')
      RETURN
C-----------------------------------------------------------------------
100   FORMAT (5X,14HTHE ELEMENT K(,I2,1H,,I2,2H)=)
110   FORMAT (/,5X,54HENTER THE FEEDBACK GAIN ESTIMATOR MATRIX  "K"-MATR
     1IX .,//,10X,48HDIMENSION = # STATES  NS  X # OBSERVATIONS  NO .)
120   FORMAT (//,15X,47HTHE FEEDBACK GAIN ESTIMATOR MATRIX  "K"-MATRIX ,
     1//)
130   FORMAT (//,5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELE
     1MENT?,//,10X,19HTYPE "YES" OR "NO".)
140   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
150   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
160   FORMAT (5X,52HENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED
     1)
      END
```

```
C=====================================================================
      SUBROUTINE READW (NG,WR)
C     INTERACTIVELY ENTERS "WO"  STEADY DISTURBANCE VECTOR           =
C=====================================================================
      REAL*8  WR(NG),DUM,ANSR
      INTEGER IANS,I,K
      DATA IY/'Y'/,IZ/'N'/
      WRITE (5,100)
      DO 10 I=1,NG
      WRITE (5,80) I
      CALL RDREAL (ANSR)
      WR(I)=ANSR
10    CONTINUE
C----------------------------------------------------------------------
20    CALL FRTCMS ('CLRSCRN ')
      WRITE (5,110)
      WRITE (5,90)  (WR(I),I=1,NG)
30    WRITE (5,120)
      CALL RDCHAR (IANS)
      IF ((IANS.NE.IY).AND.(IANS.NE.IZ)) GO TO 40
      GO TO 50
40    WRITE (5,130)
      GO TO 30
50    CONTINUE
      IF (IANS.EQ.IZ) GO TO 70
      WRITE (5,140)
      CALL RDINT (IANS)
      K=IANS
      WRITE (5,80) K
      CALL RDREAL (ANSR)
      DUM=ANSR
      DO 60 I=1,NG
      IF (I.EQ.K) WR(I)=DUM
60    CONTINUE
      GO TO 20
70    CONTINUE
      CALL FRTCMS ('CLRSCRN ')
      RETURN
C----------------------------------------------------------------------
80    FORMAT (5X,15HTHE ELEMENT WO(,I2,2H)=)
90    FORMAT (F12.5)
100   FORMAT (/,5X,57HENTER THE STEADY DISTURBANCE VECTOR MATRIX  "WO"-M
     1ATRIX .,//,10X,44HDIMENSION = # PROCESS NOISE SOURCES  NG  X 1)
110   FORMAT (//,15X,53HTHE STEADY DISTURBANCE VECTOR MATRIX  "WO"-MATRI
     1X ...,//)
120   FORMAT (//5X,54HDO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEM
     1ENT?,//,10X,19HTYPE "YES" OR "NO".)
130   FORMAT (1X,51HWARNING: IMPROPER DATA ENTRY!  ENTER "YES" OR "NO".)
140   FORMAT (5X,50HENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.)
      END
```

```
C=====================================================================
C   SUBROUTINE RDREAL -- INTERACTIVELY READS A REAL NUMBER REPLY       =
C   INTO A FORTRAN PROGRAM.  IF THE USER INADVERTENLY ENTERS  A NULL   =
C   STRING THE S/R ISSUES A WARNING AND ALLOWS A RECOVERY.             =
C=====================================================================
      SUBROUTINE RDREAL (ANSR)
      REAL*8 ANSR
      INTEGER COUNT
C---------------------------------------------------------------------
      COUNT=0
10    CONTINUE
      COUNT=COUNT+1
      IF (COUNT.LT.3) GO TO 20
      WRITE (5,60)
      GO TO 40
20    CONTINUE
      READ (5,*,END=30,ERR=30)  ANSR
      RETURN
30    REWIND 5
      WRITE (5,50)
      GO TO 10
40    CONTINUE
      STOP
C---------------------------------------------------------------------
50    FORMAT (1X,64HWARNING:  NULL STRINGS ARE NOT ALLOWED, ENTER A NUME
     1RICAL VALUE.)
60    FORMAT (/////,2X,42HPROGRAM KILLED - TWO NULL STRINGS ENTERED!,/)
      END
```

```
C=============================================================================
C   SUBROUTINE RDINT -- INTERACTIVELY READS AN INTEGER REPLY                 =
C   INTO A FORTRAN PROGRAM.  IF THE USER INADVERTENLY ENTERS AN IMPROPER=
C   DATA CHARACTER THE S/R ISSUES A WARNING AND ALLOWS A RECOVERY.          =
C=============================================================================
      SUBROUTINE RDINT (IANS)
      INTEGER COUNT,IANS
C-----------------------------------------------------------------------------
      COUNT=0
10    CONTINUE
      COUNT=COUNT+1
      IF (COUNT.LT.3) GO TO 20
      WRITE (5,60)
      GO TO 50
20    CONTINUE
      READ (5,*,END=40,ERR=40)  IANS
      IF (IANS) 40,40,30
30    CONTINUE
      RETURN
40    REWIND 5
      WRITE (5,70)
      GO TO 10
50    CONTINUE
      STOP
C-----------------------------------------------------------------------------
60    FORMAT (//,5X,49HPROGRAM TERMINATION - TWO IMPROPER DATA ENTRIES!!
     1)
70    FORMAT (1X,56HWARNING: IMPROPER DATA ENTRY!  ENTER A POSITIVE INTE
     1GER.)
      END
```

```
C=====================================================================
C  SUBROUTINE RDCHAR -- INTERACTIVELY READS A CHARACTER STRING REPLY   =
C  ('YES' OR 'NO') INTO A FORTRAN PROGRAM. IF THE USER INADVERTENLY    =
C  ENTERS  A NULL STRING THE S/R ISSUES A WARNING AND ALLOWS A RECOVERY=
C=====================================================================
      SUBROUTINE RDCHAR (IANS)
      INTEGER COUNT,IANS
C     DATA IY/'Y'/,IZ/'N'/
C---------------------------------------------------------------------
      COUNT=0
10    CONTINUE
      COUNT=COUNT+1
      IF (COUNT.LT.3) GO TO 20
      WRITE (5,60)
      GO TO 40
20    CONTINUE
      REWIND 5
      READ (5,70,END=30,ERR=30) IANS
      RETURN
30    REWIND 5
      WRITE (5,50)
      GO TO 10
40    CONTINUE
      STOP
C---------------------------------------------------------------------
50    FORMAT (1X,60HWARNING:  NULL STRINGS ARE NOT ALLOWED, ENTER "YES"
     1OR "NO".)
60    FORMAT (///,5X,47HPROGRAM TERMINATION - TWO NULL STRINGS ENTERED!)
70    FORMAT (A1)
      END
```

```
C======================================================================
C  SUBROUTINE MATPRT -- DISPLAYS A TWO-DIMENSIONAL ARRAY (16 COLS. MAX)=
C  IN VARIABLE SCREEN FORMAT FOR USER EASE IN ROW IDENTIFICATION.     =
C======================================================================
      SUBROUTINE MATPRT (PRTT,NROW,NCOL)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION PRTT (NROW,NCOL)
C----------------------------------------------------------------------
      IF (NCOL.EQ.0)  NCOL=1
      IF (NCOL.EQ.1)  WRITE (5,10)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.2)  WRITE (5,20)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.3)  WRITE (5,30)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.4)  WRITE (5,40)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.5)  WRITE (5,50)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.6)  WRITE (5,60)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.7)  WRITE (5,70)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.8)  WRITE (5,80)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.9)  WRITE (5,90)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.10) WRITE (5,100)  ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.11) WRITE (5,110)  ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.12) WRITE (5,120)  ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.13) WRITE (5,130)  ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.14) WRITE (5,140)  ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.15) WRITE (5,150)  ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.16) WRITE (5,160)  ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      RETURN
C----------------------------------------------------------------------
10    FORMAT (F12.5)
20    FORMAT (2F12.5)
30    FORMAT (3F12.5)
40    FORMAT (4F12.5)
50    FORMAT (5F12.5)
60    FORMAT (6F12.5)
70    FORMAT (6F12.5,/,F12.5,//)
80    FORMAT (6F12.5,/,2F12.5,//)
90    FORMAT (6F12.5,/,3F12.5,//)
100   FORMAT (6F12.5,/,4F12.5,//)
110   FORMAT (6F12.5,/,5F12.5,//)
120   FORMAT (6F12.5,/,6F12.5,//)
130   FORMAT (6F12.5,/,6F12.5,/,F12.5,//)
140   FORMAT (6F12.5,/,6F12.5,/,2F12.5,//)
150   FORMAT (6F12.5,/,6F12.5,/,3F12.5,//)
160   FORMAT (6F12.5,/,6F12.5,/,4F12.5,//)
      END
```

```
C=========================================================================
C   SUBROUTINE MATPRT -- DISPLAYS A TWO-DIMENSIONAL ARRAY (16 COLS. MAX)=
C   IN VARIABLE SCREEN FORMAT FOR USER EASE IN ROW IDENTIFICATION.      =
C=========================================================================
      SUBROUTINE MATPRT (PRTT,NROW,NCOL)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION PRTT (NROW,NCOL)
C-------------------------------------------------------------------------
      IF (NCOL.EQ.0)  NCOL=1
      IF (NCOL.EQ.1)  WRITE (5, 10)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.2)  WRITE (5,20)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.3)  WRITE (5,30)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.4)  WRITE (5,40)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.5)  WRITE (5,50)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.6)  WRITE (5,60)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.7)  WRITE (5,70)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.8)  WRITE (5,80)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.9)  WRITE (5,90)    ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.10) WRITE (5,100)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.11) WRITE (5,110)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.12) WRITE (5,120)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.13) WRITE (5,130)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.14) WRITE (5,140)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.15) WRITE (5,150)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      IF (NCOL.EQ.16) WRITE (5,160)   ((PRTT (I,J) ,J=1,NCOL) ,I=1,NROW)
      RETURN
C-------------------------------------------------------------------------
10    FORMAT (F12.5)
20    FORMAT (2F12.5)
30    FORMAT (3F12.5)
40    FORMAT (4F12.5)
50    FORMAT (5F12.5)
60    FORMAT (6F12.5)
70    FORMAT (6F12.5,/,F12.5,//)
80    FORMAT (6F12.5,/,2F12.5,//)
90    FORMAT (6F12.5,/,3F12.5,//)
100   FORMAT (6F12.5,/,4F12.5,//)
110   FORMAT (6F12.5,/,5F12.5,//)
120   FORMAT (6F12.5,/,6F12.5,//)
130   FORMAT (6F12.5,/,6F12.5,/,F12.5,//)
140   FORMAT (6F12.5,/,6F12.5,/,2F12.5,//)
150   FORMAT (6F12.5,/,6F12.5,/,3F12.5,//)
160   FORMAT (6F12.5,/,6F12.5,/,4F12.5,//)
      END
```

LIST OF REFERENCES

1. Hall, W.E., Computational Methods for the Synthesis of Rotary- Wing VTOL Aircraft Control Systems, Ph.D. Dissertation, Stanford Univ.,Aug. 1971.

2. Walker,R.A., User's Manual for OPTSYS 4 at SCIP, Stanford Univ., Aero/Astro Dept., Dec. 1979.

3. Liu,G., User's Manual for OPTSYS 5 at CIT, Stanford Univ., Aero/Astro Dept., Aug. 1982.

4. Bryson,A.E. and Ho,Y.C., Applied Optimal Control, Hemisphere Pub. Co., 1969, (2nd Printing, 1975).

5. Bryson, A.E., "Kalman Filter Divergence and Aircraft Motion Estimators", Jour. Guidance and Control, Vol 1, No. 1, Jan.-Feb., 1978, pp. 71-79.

6. Bryson,A.E. and Hall,W.E., Controller Synthesis for a Rotary-Wing VTOL Aircraft Near Hover, Final Report under NASA Contract NAS2-5143, SUDAAR 419, Stanford Univ., Mar.1971.

7. Bryson,A.E. and Hall,W.E., Optimal Control and Filter Synthesis by Eigenvector Decomposition, SUDAAR 436, Stanford Univ., Dec.1971.

8. Wilkinson,J.H. and Reinsch,C., Linear Algebra, Springer-Verlag, 1971.

9. Ogata, K., Modern Control Engineering, Prentice-Hall, 1970.

BIBLIOGRAPHY

Gelb, A. and others, Applied Optimal Estimation, M.I.T. Press, 1974.

Ketter, R.L. and Prawel, S.P., Modern Methods of Engineering Computation, McGraw-Hill, 1978.

Kwakernaak, H. and Sivan, R., Linear Optimal Control Systems, Wiley-Interscience, 1972.

Lipschutz, S. and Poe, A., Programming with FORTRAN, Schaum's Outline Series, McGraw-Hill, 1978.

Melsa, J.L. and Jones, S.K., Computer Programs for Computational Assistance in the Study of Linear Control Theory, McGraw-Hill, 1973.

Ogata, K., Modern Control Engineering. Prentice-Hall, 1970.

Research and Educational Association, Problem Solver in Automatic Control Systems/Robotics, 1982.

Sage, A.P., Optimum Control Systems, Prentice-Hall, 1968.

Wilkinson, J.H., The Algebraic Eigenvalue Problem, Clarendon Press, 1965.

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